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GEOLOGICAL MAGAZINE

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On the Origins of the Kumaon Lakes in the Himalayas

By A. N. THOMAS

ABSTRACT

Numerous small lakes in the Naini Tal region of Kumaon have long attracted attention but no satisfactory explanation of their origins has been presented. The various lakes did not all originate in the same way in spite of their proximity, but there must be common underlying conditions to explain the abundance of lakes in this small area. These conditions appear to be the very recent and very local irregular uplift of a mass of diverse lithological units riding over an irregular sub-thrust surface.

INTRODUCTION

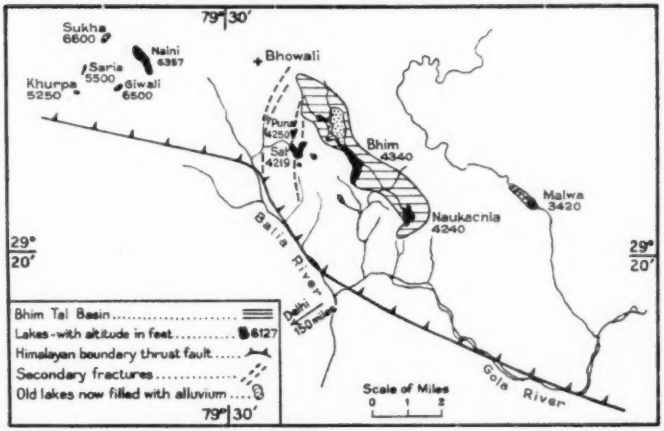
APART from the lakes of Kashmir, those of Kumaon, about 150 miles N.E. of Delhi, comprise the only large group of lakes in the Himalayan region of India. The origin of the group has given rise in the past (1877 to 1890) to a considerable amount of speculation, but the question has never been satisfactorily settled and of late it has not received much attention. The lakes of Kumaon lie in a belt 15 miles long and 2 miles broad near the border of the "Sub-Himalayan Zone", which is a maturely dissected peneplain some 30 miles wide, lying at an altitude of 8,000 feet between the Siwalik hills to the south and the Great Himalayan range to the north.

While on short leave from the Indian Army the writer studied the Kumaon lakes, with the exception of Malwa Tal, in the field and arrived at various hypotheses of origin. It soon became evident that in spite of the close proximity of the lakes, no one explanation could be found to account for all of them. It is clear that any explanation of the origin of the lakes will be inadequate unless it also accounts for all the associated geomorphological features, and is in accord with the regional geological and physiographic picture.

It is important to recognize the difference between proximate causes and more remote causes. Although the proximate causes and modes of development of the various lakes in the Kumaon group seem to be very different, there should be common underlying

conditions which can explain the abundance of lakes in Kumaon and their rarity elsewhere in the sub-Himalayan zone.

Previous explanations of the lake origins are noteworthy for the controversy between Ball (1878), who believed in a landslip origin, and Theobald (1880), who strongly supported a glacial origin, as did Blanford before him (1877). Oldham (1880) supported Ball's theory of landslip origin and Holland (1894) described the formation of the Gohna lake by landslipping in the Garwhal Himalaya. Medlicott



TEXT-FIG. 1.—The Kumaon Lake District.

(1881) suggested that hypogene ground movements may have played a part, while Middlemiss (1890) suggested differential uplift and subsidence along groups of fractures which cannot be demonstrated in the field, aided by solution of the local limestones.

The Swiss geologists, Prof. A. Heim and Dr. A. Gansser (1939) regard Ayarpatha as a very broken structural mass, and Gansser's idea was that the whole region south-west of the lake had been affected by late or post-tectonic sagging, thus causing the breaking up of the stratification. They mention a claim by Gerlach to have established the existence of a moraine in lakes adjacent to Naini Tal.

Dr. J. B. Auden (1942 *a*) made the first modern stratigraphical correlation of the strata around Naini Tal, and his geological map, for which he makes no claims to either completeness or accuracy, is a great advance. He agrees with Heim and Gansser that a much larger area should be shown as " slipped ". The stratigraphical and structural successions of the Krol Belt (1934) and the Garwhal region (1937) are also described by Auden.

General Stratigraphy and Structure

The stratigraphical succession in the Kumaon Lake region is :—

Superficial Deposits, including landslip material.
Siwalik sandstones.

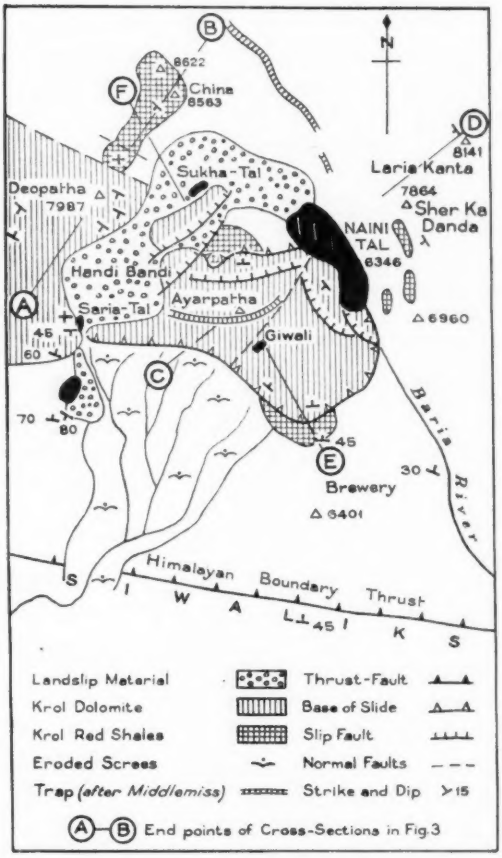
Himalayan Boundary Thrust

Upper Krol Dolomites.
Krol Red Shales with bands of dolomite : a potentially plastic horizon.
Lower Krol Slates.
Blaini Series. Banded Carbonaceous Slates.
Nagthat Quartzites.
" Greenstones " and Slates.
Intrusive " trap ".

From the standpoint of this paper it is only important to note that Naini Tal and its ancillary small lakes (Text-fig. 2) are situated amongst the outcrops of Krol Dolomites and Slates, while the Bhim Tal group of lakes (Text-fig. 3) is situated amongst the Nagthat Quartzites and the Greenstones and Slates which underlie them. For more detailed descriptions of the stratigraphy reference may be made to published reports.

The principal structural feature of the immediate vicinity is the Himalayan Boundary Fault, which appears to be a high-angle thrust carrying folded strata of the Krol–Nagthat series from the north over folded Siwalik rocks to the south. The trend of the fault is in general from west-north-west to east-south-east, but opposite Bhim Tal there is a change to a north-west to south-east direction along the Balia River. This change is caused by a bulge forward of the over-thrust rocks in the area containing the Bhim Tal group of lakes, and is associated with the development of secondary fractures aligned north to south in the Sat Tal region (Text-fig. 4). According to Dr. Auden (personal communication) the Krol Nappe often rests with violent tectonic discordance across the strike of the underlying Siwaliks and was formerly overridden by the megatectonic Garwhal thrust carrying forward phyllites, schists, and gneisses of the Dudatoli–Raniket–Almora zone.

Minor structures affecting the Krol–Nagthat succession are by no means fully known. The whole series appears to be thrown into folds aligned in a N.W. to S.E. direction. Ridges of pre-Nagthat green-stones with this trend are seen at Bhowali and to the north and south of Bhim Tal. The overlying Krol Slates are folded into a generally synclinal area about Naini Tal, with a pitch to the west. Between Deopatha and Khurpa Tal (Text-fig. 2) there is a series of steep folds in the Krol Dolomites. The main syncline under Deopatha has a steep



TEXT-FIG. 2.—Geological sketch-map of Naini Tal.

northern limb, which is cut off by a fault. North of the fault, Krol Shales and Krol Red Shales with thin limestones are to be seen dipping gently southward from China Peak.[1]

The Ayarpatha dolomite mass lies along the strike of the steeply folded Deopatha syncline, but there is no sign of the steep folds or even of a synclinal arrangement of the beds. Gentle northerly dips appear to prevail over most of the mass and a few southerly dips on the northern side are clearly connected with post-tectonic slipping. In the great cliff which forms the southern face of Ayarpatha there appears

[1] Pronounced *Cheena*.

to be a low-angled thrust hading towards the west, within the dolomites. Several similar thrusts have been suggested by Dr. J. B. Auden within the Krol Slates west of China Peak and along the ridge to Sher-Ka-Danda. Apart from field indications of these low-angled thrusts, he points out that the great apparent thickness of calc-slates here as compared with elsewhere requires some degree of repetition. From many points of view therefore the tectonic structure of Ayarpatha suggests that it is a continuation of China Peak rather than of Deopatha. It will be seen from what follows that this is a fact of some importance in working out the structural history of the Naini Tal area.

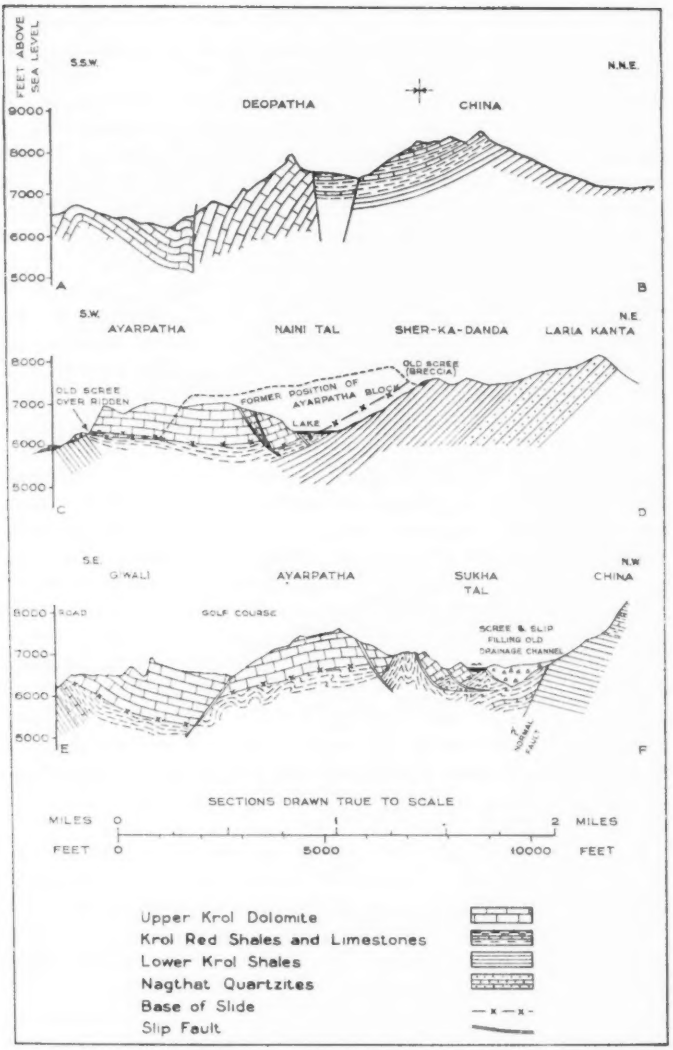
Post-Tectonic Structures.—Evidence of post-tectonic structures is to be found around Naini Tal (Text-fig. 2). Prof. A. Heim and Dr. A. Gansser (1939) thought that the whole region south of the lake had been affected by post-tectonic sagging. The writer agrees, but believes also that the Ayarpatha mass has moved as a unit from a position further to the north, becoming broken up in the process. It is similar to the " slipped blocks " described by Dr. J. V. Harrison and Mr. N. L. Falcon (1934) as " gravity collapse structures " in Iran. On the north and south flanks of Ayarpatha are outcrops of Krol Red Shales which form the " plastic " horizon over which the block must have slipped. The base of the slide as shown on Text-fig. 2 is discordant over the underlying formations and the junction at the discordance is clearly exposed in the cuttings of the new road from Kathgodam to Naini Tal. Below the base of the dolomites the underlying shales are contorted and broken up and contain angular fragments of the overlying dolomites ranging from pebble size to large blocks several feet in diameter. It is clear that this junction is not an unconformity. The observed facts seem to indicate a sliding forward of the Ayarpatha dolomites over the Krol Red Shales. The sliding mass has overridden its own scree, which is now represented by the angular fragments below the base of the slide.

By contrast with Naini Tal, there is no evidence of post-tectonic movements in the country around Bhim Tal. The ridges to the south of Bhim Tal have very deep roots which extend below the bottom of the ravine that drains the waters of the lake (Text-fig. 4). This contrast suggests at once that the modes of formation and detailed geological histories of the various lakes may have been very different.

Explanations of Lake Origins

(*a*) *The Naini Tal Group*

Any theory which attempts to explain the origin of Naini Tal must also explain the associated peculiar geomorphological features of the countryside. Theobald (1880) was convinced that the barrier at the south-east end was a glacial moraine, but an examination will



TEXT-FIG. 3.—Geological cross-sections through the Naini Tal Basin.

soon convince anyone as it did Oldham (1880) that the barrier is formed of a slipped block of limestone with debris and later adjustment slipping. The associated landscape has none of the features which are normally

associated with glaciation. There are no cirques, no U-shaped valleys, no smooth and polished rocks, no striae, no erratics, and no moraines.

The smooth even slopes of the ridge running from China Peak to Sher-Ka-Danda and onwards are not like those of a glaciated valley but are consistent with the suggestion that they were protected from erosion by the Ayarpatha dolomite before it slid into its present position. After the slide took place the slope has been kept graded by rain wash and landslip. The enormous hollow between China Peak and Deopatha on one side and Ayarpatha on the other side, and which was formerly much deeper, cannot be explained as a normal erosional feature. It requires the bodily removal of a large mass of dolomite, of which fragments now remain in the detached masses of Handi Bandi Hill and the Sukha Tal ridge. Less completely detached masses can be seen separated only by cracks from the northern side of Ayarpatha.

It is believed that the probable sequence of events was as follows. After the folding and thrusting of the Krol–Nagthat belt, erosion succeeded in isolating an inclined block of Krol Dolomite (Text-fig. 3, section C.D.) lying south-eastward along the strike from China Peak and separated from it by dip-faults throwing to the south-east (Text-fig. 3, section E.F.). This inclined block was tilted south-westward and lay on top of the potentially plastic Krol Red Shales. Under the influence of gravity, and assisted by late earth movements the inclined block moved southward towards lower ground, buckling the underlying beds and coming to rest in a horizontal attitude as the broken dolomite mass of Ayarpatha. An enormous chasm was left between Ayarpatha and its neighbours, and has since been partly filled by landslip, scree, and outwash.

Along the northern side of Ayarpatha there are several more or less detached blocks of the dolomite, including the central rise in the lake bed, ranging up to more than a mile in length. They are separated from the main mass by " slip-faults " (Text-fig. 3, sections C–D and E–F), which are purely superficial fractures, some of which are still open or only partially infilled by detritus. In the movement southward of the main mass the smaller blocks were detached from its northern side by frictional drag. Exposures of the Krol Red Shales in this area show considerable disturbance. J. B. Auden (1942a) has suggested that " the Handi Bandi dolomites have possibly subsided without much lateral movement on the underlying Krol Shales, which are easily lubricated and may have been squeezed out with resulting collapse of the overlying dolomites. The Sukha Tal dolomites, on the other hand, appear to have slipped laterally from the north side of the western slopes of Ayarpatha ". The Handi Bandi dolomites, however, lie between the Sukha Tal dolomites and the

Ayarpatha dolomites. It seems preferable to regard the detached blocks as fragments left behind by the Ayarpatha mass in its move south rather than as blocks which have slipped northward from the mass in situ. They may, of course, have also slipped laterally or vertically after their detachment.

The principal evidence for the Ayarpatha slide is the discordance with underlying beds exposed in the Kathgodam–Naini Tal road cutting which can only be interpreted as a slide that caused the dolomite mass to override its own scree material (Text-fig. 3, section C.D.). This point has already been discussed under the section on post-tectonic structures. Secondly, cemented dolomite breccias are to be found on the slopes of Sher-Ka-Danda, and some of these may be most easily interpreted as scree from the dolomite in its former position. Heim and Gansser show limestones interbedded in the Krol Slates, and the exact interpretation of each outcrop is complicated by the occurrence of contemporaneous dolomitic breccias in the Krol Red Shales. Thirdly, the general quasi-horizontal attitude of the dolomites in Ayarpatha, contrasts with the highly folded nature of the beds along the strike in Deopatha (compare sections A.B. and C.D. in Text-fig. 3), while it accords with the uniform and gentle dips observed on China Peak, along the strike from its former putative position.

An interesting piece of collateral evidence is the course of the " trap " which is shown on Text-fig. 2. This is visible on the north side of the ridge between China Peak and Sher-Ka-Danda, is then lost and picked up again on the Ayarpatha dolomite mass. This distribution is also most easily explained by the supposition that Ayarpatha was formerly in a more northerly position.

The enormous open chasm of bare unprotected rock between Ayarpatha and Deopatha must have been subjected at first to very rapid erosion which cut down well below the base of the slide at the north-west end of Naini Tal and caused further subsidence of the detached blocks of Handi-Bandi and Sukha Tal. The products of this erosion were deposited beyond the debouchment at Saria Tal blocking a small side valley to form Khurpa Tal. Undermining of the sides of the chasm by erosion caused large subsidiary landslips which in time have partly filled in the chasm. On the undulating surface of the landslip material were numerous hollows of varying size, some dry, others occupied by temporary lakes such as Sukha Tal and Saria Tal. Naini Tal itself was formed more as a result of these landslips which block its north-west end than as a result of the slipped block which blocks its south-east outlet.

The above explanation of the origin of Naini Tal and its associated geomorphological features is essentially simple : after the initiation of the slide all the other processes and events follow in normal causal

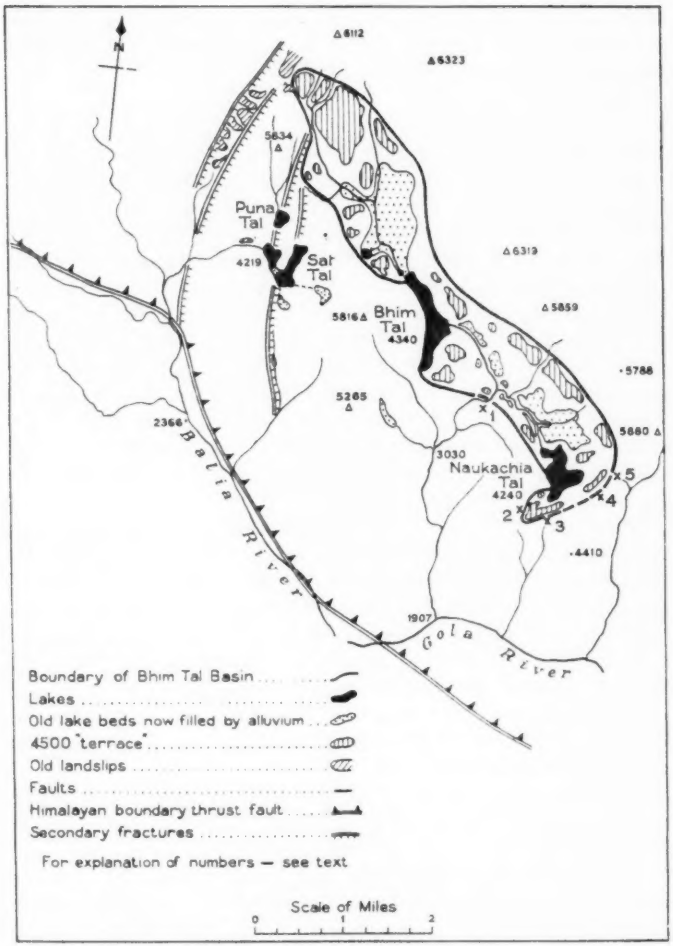
relationship. The geological evidence favours the idea of a slide and the geomorphological evidence reinforces this explanation. No other theory appears to fit the observed facts.

(*b*) *The Bhim Tal Group*

The Bhim Tal group includes Bhim Tal, Naukachia Tal, Sat Tal (= seven lakes), and Puna Tal, together with some very small dry lake beds which appear to be related. Much more geomorphological and geological work will have to be done before the origin of the Bhim Tal basin and the contained lakes can be regarded as satisfactorily explained. The brief examination by the author was, however, sufficient to show that the proximate causes of origin of these lakes must be very different from those of Naini Tal. There is no evidence of large-scale gravity sliding around Bhim Tal such as was invoked to explain the geomorphological features associated with Naini Tal. On the contrary the ridge of high ground to the south of Bhim Tal and Naini Tal is composed of pink quartzites and dark green basic igneous rocks, with slates and laminated tuffs, which have deep roots extending below the deepest level of present-day erosion.

Text-fig. 4 illustrates some of the principal morphological features associated with the Bhim Tal group of lakes. It is clear that Bhim Tal formerly extended considerably further to the north, over the alluvial gravels. A low-lying dissected alluvial terrace between Bhim Tal and Naukachia Tal, shows that these lakes were formerly connected, and it seems likely that the original lake was about four miles long and half a mile wide. The present surface of Naukachia Tal is 100 feet lower than the surface of Bhim Tal. Naukachia Tal is shrinking fast since most of its former headwaters have already been diverted into the stream which drains Bhim Tal.

Around the lakes is a ring of morphological " terraces " at a present elevation of 4,500 feet above sea-level and entirely contained within the Bhim Tal basin. A possible explanation of this ring of " terraces " is that the level of the combined lake stood at this level, 250 feet above the present level of Naukachia Tal, while the surrounding country was graded to a profile which had a local base level at the lake surface. It is doubtful, however, whether such a temporary feature as this large lake would have remained long enough to permit grading. An alternative explanation of the " terraces " is that they are part of the base-level which is now buried beneath the plains of Northern India, elsewhere eroded away. Against this hypothesis is the lack of any evidence of terraces or graded profiles related to this level in the adjoining valleys outside the Bhim Tal basin. On the other hand all tributaries of the Gola River have cut back deeply into the surrounding country and have nearly cut back into the Bhim Tal basin



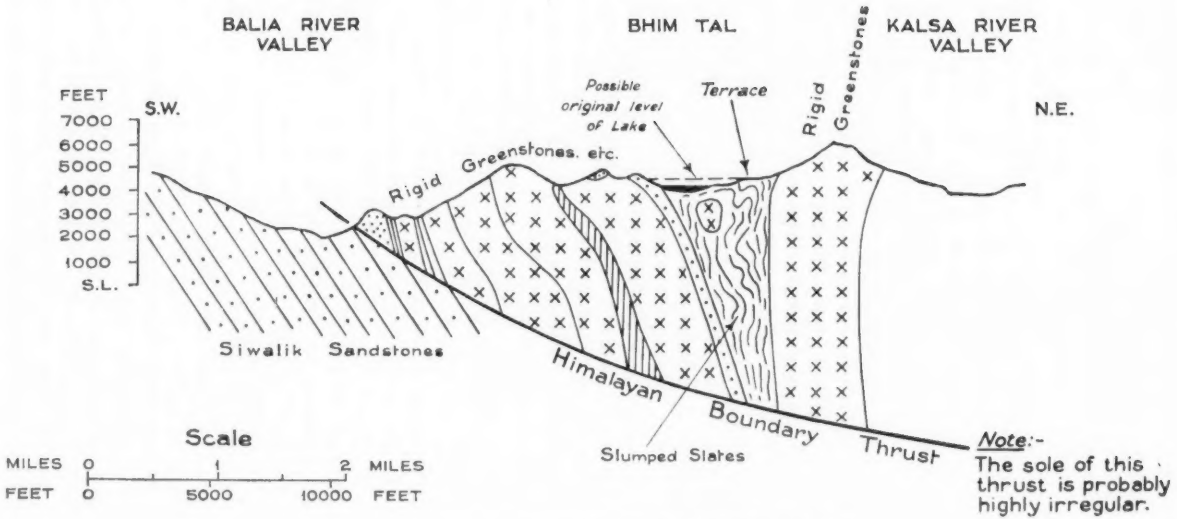
TEXT-FIG. 4.—The Bhim Tal group of lakes.

itself at points marked 2, 3, 4, and 5 on the map, and so would have removed evidence which formerly may have existed. It is evidently important to decide whether the terraces post-date or ante-date the lake in formation and this cannot be done without a detailed morphological survey of the Himalayan front.

The derivation of the present Bhim Tal and Naukachia Tal from

one large lake is easy to understand. It is more difficult, however, to explain the origin of the whole basin with its highly irregular floor depressed for 300 feet or more below the " terrace " level. The barrier to the S.W. of the basin has deep roots and so cannot have originated by gravity sliding. It is possible, however, that after uplift an intermontane plain or " Dun " represented by the terraces was deeply eroded and subsequently blocked by landslip. The barrier to the south-east of Bhim Tal at first sight looks morainic. It consists of two large hillocks, which in stream cuttings are seen to be composed of large and small boulders set in a clayey matrix, bearing a superficial resemblance to boulder clay. Examination of the deposit, however, shows that it is composed entirely of deeply weathered basic igneous rock ; the well rounded boulders, pebbles, and matrix being merely degrees of weathering in situ of the parent material. There is no sign of the quartzites, tuffs, or slates which occur in the surrounding hills and which would certainly be present in a true glacial deposit. A landslip, however, need contain only material from the immediately adjacent hillside, which in this instance is composed of basic igneous rock.

The barrier may, however, have been an original hillock of tectonic origin in the basin floor. The writer has seriously considered the hypothesis that geologically very recent earth movements had caused differential elevation. This was put forward by H. B. Medlicott (1881) who said " in a very heterogeneous mass of contorted rocks intense lateral pressure below may often result in the local squeezing up of a more rigid mass of rock, or one of which the bearings lend themselves to such a result of resistance ". In the Bhim Tal region the quartzites and basic igneous rocks were the rigid masses while the slates and weathered rocks were the less rigid members of the heterogeneous assemblage. The proximity of the outcrop of the Himalayan boundary thrust suggests that the rigid masses had their bearings directly on the sole of the thrust and thus suffered maximum upward displacement while the less rigid formation in the centre of the Bhim Tal basin slumped back in irregular hollows (Text-fig. 5). Prof. A. Heim (personal communication) draws attention to the uneven Siwalik basement of the Krol thrust and supposes that the uneven erosional surface of the Siwaliks caused the first breaking up of the thrust mass. Splinters of the competent formations would form irregular hillocks in the basin floor. Heim and Gansser (1939) have shown that the Himalayan thrust mass has advanced recently south of Bhim Tal along a break in the strike of the Siwaliks. The course of the boundary fault shows clearly that there is a bulging forward of the Himalayan thrust mass and that this is associated with tensional or tear-faults, trending southward through Puna Tal, Sat Tal, and a landslip-filled parallel valley to the west. There is no clear evidence to show that Sat Tal



TEXT-FIG. 5.—Schematic cross-section of the Bhim Tal region.

and Puna Tal are landslip-blocked. There are numerous small landslips in the very similar fault cracks to the west and such landslips may have blocked these small lakes, but the effects of possible differential movements along the tensional faults remain to be investigated.

There is, however, an objection to Medlicott's theory. Under compression it is usually the incompetent formations not the rigid rock masses which are squeezed up highest. The lower topographic level of the incompetent formations could be caused by a later tensional phase succeeding the initial compression or by differential erosional activity. Uplift of the sub-Himalayan zone after the cessation of compressional movement would have introduced a tensional phase during which differential slumping of the incompetent slates could have produced the irregular floor of the Bhim Tal basin.

The above suggestions are put forward tentatively in the hope that further field work by geologists in India will resolve the problem. The solution will require a combination of geological and morphological investigation. A careful study will have to be made of the barriers, bearing in mind that the present barriers are not necessarily the original ones. The relative ages of formation of the lake and the 4,500 ft. terrace also need investigation and relating to the stages of earth movement, particularly the most recent uplift and its topographic expression.

So far as our present knowledge goes two hypotheses of origin seem possible :—

(i) An intermontane plain has been uplifted, eroded, and then blocked by landslip.

(ii) A belt of relatively incompetent slates has slumped irregularly during the later tensional phase of uplift of the sub-Himalayan zone.

Underlying Conditions

In the introduction it was stated that all the Kumaon lakes must have been formed under common underlying conditions. Lakes are extremely rare in the sub-Himalayan region and there must be some reason for their abundance in this small area. If the explanations given above are correct, the Kumaon lakes were very different in proximate causes and historical development. Naini Tal was caused by the erosion and landslip infilling of a hollow left by gravity sliding. Bhim Tal and Naukachia Tal are two relics of a much larger single lake, which was caused by ground slump movements or by erosion and landslip. Malwa Tal may have been caused by a simple landslip in a similar fashion to the Gohna Lake in Garwhal. The smaller lakes are equally diverse in origin. The Sat Tal group seem to have originated in tensional fault cracks, possibly assisted by landslip. Khurpa Tal

was blocked by a landslip flow across a small valley. Sukha Tal and Saria Tal appear to occupy original hollows within the deposits of a large landslip.

The factors which appear to have conditioned lake formation in Kumaon are :—

(i) Very recent earth movement.

(ii) Diversified lithology.

There is evidence to show that the Himalayas have moved south-westward in very recent geological times. Heim and Gansser (1939, figs. 9 and 10) showed that recent terraces in the Siliguri district were affected. They also showed that in several places the Himalayas were thrust forward over an old eroded surface. In two places east of the Tista the thrust has carried the Darjeeling gneisses on to the terraces of the Siliguri plain through gaps previously eroded in the Siwalik hills. Another of these " relief thrusts " has developed in the Naini Tal region and the older rocks have moved forward into an erosional break in the Siwalik hills. Lack of resistance from the eroded Siwalik foreland allowed the Himalayan rocks to move forward rapidly, setting up tensional faults through Sat Tal. In support of the idea of very recent movements Dr. Auden informs me that possible seismic faults occur along the south side of the Giri valley in Sirmur State (now Himachal Pradesh), and in the Kosi valley of Nepal (Auden, 1942 *b*). There are also tear faults in the Siwaliks now occupied by the Jumna and Ganges rivers.

In the Darjeeling Himalaya tectonic instability is accompanied by a uniform gneissic lithology. There are no large units of differing lithology and no potentially plastic formations to form big unstable topographical units. The relief is high, and landslips and rock-flows are of common occurrence, but such slips are not of great size. The rainfall incidence is mostly in the four months June to September, and during this period hundreds of inches of rain may fall. The ground is soon saturated, evaporation is reduced by cloud cover, and most of the rainfall is available as run-off. If a barrier were to form across a valley a lake would form very rapidly and surmount or erode the barrier before it had time to consolidate.

In the Kumaon area the lithological units are more diverse. The competent formations were resistant to erosion, while the incompetent beds were easily eroded, and liable to slumping. As a result of rapid uplift, high rainfall, and rapid erosion a high relief was soon developed. Rock slides and landslips were aided by the plastic red shales and easily lubricated slates present in the succession.

Lakes of this size are but temporary geological features. Their frequency in this small region at this time must be connected with a

very recent, rapid, and irregular local movement. The irregular eroded surface of the Siwaliks over which the Krol Nappe has moved must have contributed to the formation of surface irregularities consequent on the breaking up of the thrust mass.

The Kumaon lakes are not the only ones which can be related to recent earth movements in the Himalayan region. In the Punjab States the Kundlu lake was noted by Medlicott. In Jammu province small lakes (Suruin Sar and Man Sar) occur on the crest of an eroded Siwalik anticline into the core of which large blocks of the more resistant formations have slipped to form lake barriers. Dr. P. Evans has drawn attention to Assam where the big Nawng Yang lake (set in a vast marsh) and several smaller lakes and marshes are assumed to have been produced by small local uplifts within the past few hundred years. He also points out that the earthquake of 15th August, 1950, seems to have produced landslips on a very large scale. Dr. Auden (1942 *b*, Plate 9) shows a series of small lakelets caught in between the Krol and Nahan thrusts between Bakan and Achhaun and notes that they are probably seismic. Apparently small lakes of seismic plus landslip origin are more widespread in the Himalayan region than is generally supposed.

Acknowledgments

The writer acknowledges his debt to Dr. J. B. Auden, of the Geological Survey of India, who has kindly allowed him to read his unpublished report, and to Dr. G. M. Lees, F.R.S., who has read the original and suggested modifications which appear in the text and text-figures. Professor Heim, Dr. A. Gansser, Dr. Auden, Dr. P. Evans, and Mr. S. V. Sykes have recently read the manuscript and have made useful suggestions and modifications.

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Maps

Survey of India : Quarter inch to 1 mile sheet 53–0.
One inch to 1 mile sheets 53–0/7 and 53–0/11.
Six inch to 1 mile Naini Tal Guide Map.

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The Position of the Falkland Islands in a Reconstruction of Gondwanaland

By Raymond J. Adie

Abstract

In previous reconstructions of Gondwanaland the Falkland Islands have been placed in a position intermediate between the Cape Province and Northern Argentina. In the present paper it is suggested on structural, tectonic, and stratigraphical grounds that it would be preferable to position the Falkland Islands due east of the Eastern Province coast, thus completing the truncated Karroo Basin, the missing part of which has until now been suspected to be concealed beneath the ice-capped Queen Maud Land, Antarctica.

Introduction

IN the majority of previous reconstructions of Gondwanaland the Falkland Islands have been either summarily dismissed as unimportant or neglected completely.

It has long been recognized that the Falkland Islands bear no stratigraphical or structural relation to Patagonia (du Toit, 1927, p. 16). Du Toit's view (1937, p. 55) that these islands are one of " the far-travelled masses " is indeed true, since in the light of recent evidence (Adie, 1952) the stratigraphy of the Falkland Islands can be correlated closely with that of South Africa.

A problem which has faced South African geologists for a long time is that of the truncated Karroo Basin in south-eastern Africa. This has been temporarily solved by suggestions that the south-eastern coast of Natal is a fault-coast, associated with the Natal monoclinal flexure (King, 1940) and the subsequent disruption of Gondwanaland But where is the missing portion of the Karroo Basin to be found now ? King (1950) has suggested that the Karroo sediments together with their capping of Drakensberg lavas should perhaps be sought in Queen Maud Land and Coats Land in Antarctica.

The author has no intention of discussing here the main bone of contention between the supporters and opponents of continental drifting, namely, the mechanics of the disruption of Gondwanaland.

Stratigraphical Correlation

A detailed correlation of Falkland Island and South African stratigraphy has already been treated *in extenso* elsewhere (Baker, 1922 ; du Toit, 1929 and 1937 ; Adie, 1952). It is therefore unnecessary to survey the evidence for the stratigraphical correlation here. The following table, including a correlation with Brazil, Uruguay and Argentina, is given for the reader's convenience.

CORRELATION OF FALKLAND ISLAND, SOUTH AFRICAN AND SOUTH

Europe.	*Falkland Islands.*	
RHAETIC . . .		
U. TRIASSIC . .	West Lafonian Beds	
	Bay of Harbours Beds	
U. PERMIAN . .	Choiseul Sound and Brenton Loch Beds	
LOWER PERMIAN . .	Lafonian Sandstone	
LOWEST PERMIAN . .	Black Rock Slates	
	Lafonian Tillite	
U. CARBONIFEROUS .	Bluff Cove (Fitzroy Basin) Beds	
	~~	
L. CARBONIFEROUS .	Port Stanley Beds	(T)
M. DEVONIAN . .	Port Philomel Beds	(T)
Late L. DEVONIAN .	Fox Bay Beds	(M)
L. DEVONIAN . .	Port Stephens Beds	(M)
	~~	
ARCHEAN . . .	Cape Meredith Complex	

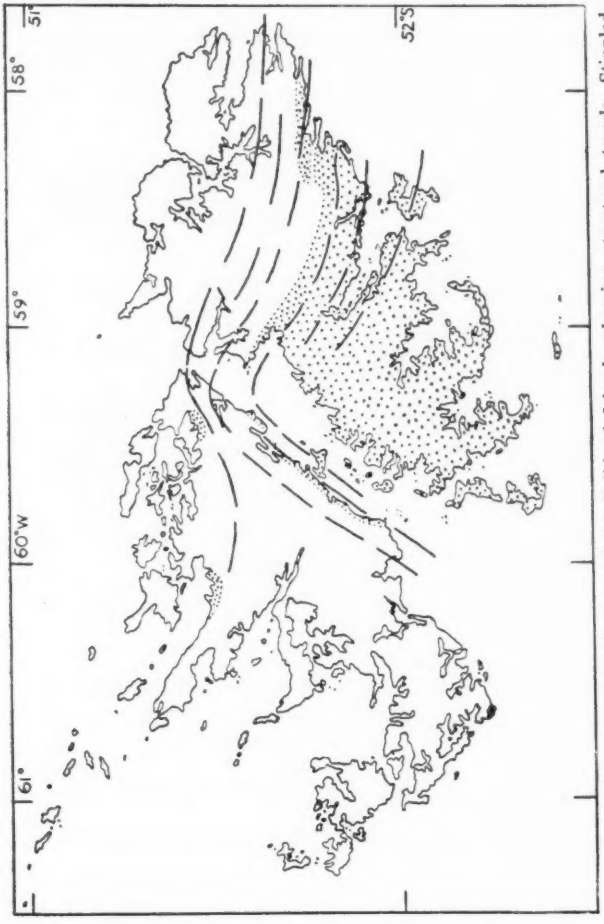
The wavy line denotes a *disconformity* or *unconformity*.

(T) = Terrestrial sediments.
(M) = Marine sediments.

AMERICAN STRATIGRAPHY (after BAKER, 1922, and ADIE, 1952)

South Africa.		*Brazil, Uruguay, and Argentine.*
Drakensberg Volcanics	=	Serra Geral Eruptives
Cave Sandstone	=	Botucatú Sandstone
Red Beds		
= Molteno Beds to U. Beaufort Series	=	Rio do Rasto Beds / Upper Estrada Nova Beds
= M. Beaufort Series to L. Beaufort Series		
		~~ (?)
= L. Beaufort Series to Upper M. Ecca Series		
= Lower M. Ecca Series		
= L. Ecca Series to U. Dwyka Shales	=	Lower Estrada Nova Beds
	=	Iratý Shales / Rio Bonito Beds
= Dwyka Tillite	=	Itararé Beds
= L. Dwyka Shales		
		~~
= Witteberg Series	=	Barreiro Sandstone (B)
= U. Bokkeveld Series (T)		
	=	Ponta Grossa (B)
	=	Rincon de Alonso (U)
= L. Bokkeveld Series		
= Table Mountain Series (M)	=	Furnas Sandstone (B)
	=	Carmen Sandstone (U)
	=	Sierra de la Ventana Quartzites (A)
~~		~~~~
= Basement Complex	=	Basement Complex

(B) = Brazil
(U) = Uruguay
(A) = Argentine



TEXT-FIG. 1.—Geological sketch map of the Falkland Islands, showing structural trends. Stippled, Gondwana System; plain, Devonian System; black, Archean; and heavy dashed line, trend of fold-mountain system.

PALAEONTOLOGY

The valuable palaeontological work of Andersson (1907), Hallé (1912), and Baker (1922) has shown that some twenty-one Falkland Island mid-Devonian marine species have identical counterparts in the South African Bokkeveld Series. From this it may be inferred that similar climatic and marine depositional conditions existed in both localities at this time. It is hoped that future exploration of the

Falklands will bring to light further material suitable for correlation purposes.

The Permo-Carboniferous Glaciation

In the southern Cape Province there is a gradual conformable transition from the Witteberg Series into the Lower Dwyka Shales and subsequent Main Tillite. It has been recognized that these beds resulted from continental ice-sheets discharging their detrital load into reasonably deep fresh-water, whereas in the Natal area the Tillite is terrestrial and is unconformable upon the Table Mountain Series.

The Cape Province Dwyka Shales correspond to the *locally occurring* Bluff Cove (Fitzroy Basin) Beds of the Falkland Islands, and in the author's opinion both are of similar origin. Although the Bluff Cove Beds are coarsely bedded at the bottom, " lamination becomes very pronounced towards the top, and elongated boulders up to 4–5 inches in length are frequently observed with their long axes perpendicular to the bedding planes of the laminated shales " (Adie, 1952). This evidence clearly indicates that at the onset of glacial conditions discharge of debris from glacier fronts took place under marine or fresh-water conditions. Their basin-like and purely local occurrence supports the latter hypothesis rather than the former.

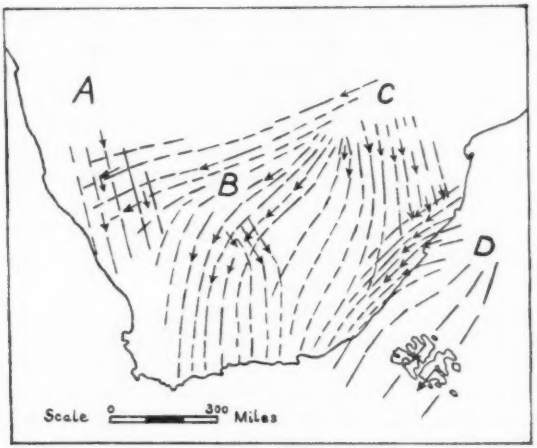
Succeeding the Bluff Cove Beds is the Lafonian Tillite, which is massive and more indicative of terrestrial than marine or fresh-water conditions. It is possible there was a temporary regression of the water's edge during this phase of deposition. On the other hand the several isolated tillite exposures of the West Falklands are typically terrestrial and are indistinguishable from the tillite of Natal.

" White Band "—*Mesosaurus*.

Mesosaurus is found in both the " White Band " of the Cape Province Dwyka Series and identical Iratý Shales of Brazil and Uruguay. The marked absence of this small aquatic reptile in the Falkland Islands is perhaps a significant point, suggesting that these corresponding Falkland strata formerly occupied a position beyond the limits of the lateral extent of *Mesosaurus*. The Falkland Black Rock Slates, which are the temporal equivalent of the Upper Dwyka Series, may be considered as representing a transitional fluvio- or limno-glacial phase originating towards the end of the glacial period (Adie, 1952). With eastward lateral thinning of the " White Band " the prominence of a cherty band is increased. It is possible that the " White Band " itself is represented in the Falklands by a prominent cherty horizon within the Black Rock Slates. This difference in facies between the Cape Province and Falkland Islands may explain the absence of *Mesosaurus* at the horizon where it would otherwise certainly be expected to appear.

Glacial Striae.

From a study of glacial pavement striation directions, du Toit (1939, p. 245) has shown very clearly that during Permo-Carboniferous times at least four distinct centres of glaciation existed in South Africa. Outflow from these took place radially, but later glacial phases have tended to destroy striations resulting from earlier phases. On these grounds the Natal ice centre may be considered as being the youngest of these four ice centres (see Text-fig. 2). When he made



TEXT-FIG. 2.—Map showing the perfect "fit" of Falkland Island glacial striation directions into the Permo-Carboniferous Ice radiation pattern reconstructed by du Toit (1939, p. 245). A, Namaqualand; B, Griqualand West; C, Transvaal; and D, Natal Ice Centres. (Map after A. L. du Toit.)

his reconstruction of the late Carboniferous glacials in Gondwanaland, du Toit (1937, p. 76) had no access to the recently disclosed significant fact that in the Falklands *the glacial striae indicate flowage of ice from south to north.* This new information definitely does not fit in with du Toit's reconstruction.

It is suggested that by inverting the Falkland Islands north to south and placing them in the position shown in Text-fig. 2 the glacial striae fit in admirably with the striation directions recorded in Natal.

LOWER PERMIAN COAL MEASURES

The South African Coal Measures (Middle Ecca Series) are Lower to Middle Permian in age, with their near-maximum development

of 1,100 feet at Dundee, northern Natal. In south-eastern Natal (north-west of Pietermaritzburg) the Middle Ecca thins remarkably to 600 feet and carbonaceous lenses take the place of the thick northern Natal coal seams. Along the coast, on the seaward side of the Natal Monocline, the Middle Ecca Series is again represented, but is entirely devoid of carbonaceous material.

Bearing in mind the lateral thinning and diminution of carbon content towards the south and south-west, it is not surprising to find that the Falklands Lafonian Sandstone is no more than 300 feet thick (Baker, 1922), and contains no coal deposits or even carbonaceous lenses ; it nevertheless retains its characteristic arkosic nature.

Karroo Dolerites

It is doubtful whether basalts of the Drakensberg type ever covered the Falkland Island Gondwana sediments in the past. It they had, the covering must have been extremely thin and has been subsequently stripped off by erosion. In northern Uruguay the Rhaetic plateau basalts do not exceed 800 feet in thickness, but thicken northward into Brazil, where in places they lie directly upon the Basement Complex.

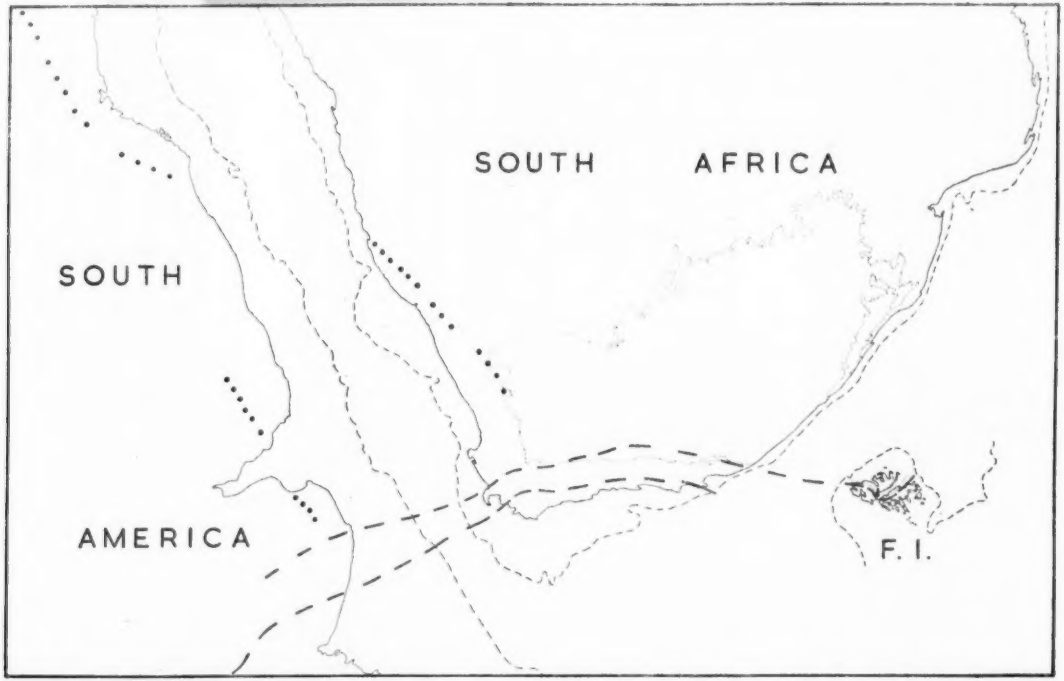
The Falkland dolerite dykes (Andersson, 1907 ; Hallé, 1912), some of which are olivine-bearing, are petrographically identical to some of those described from South Africa by Walker and Poldervaart (1949). On petrographical grounds they are regarded as Karroo in age, but nowhere are they seen to intrude the Falklands Gondwana beds either as sheets or dykes. As in the southern Cape Province fold belt, the dolerites are confined to the Devonian sediments which they intrude as narrow dykes parallel to the fold axes.

Since the Falkland Gondwana beds are also folded in places, it may be inferred that they represent the eastwards continuation of the Karroo Basin, south of du Toit's (1939, accompanying map) " southern limit of Karroo dolerites ".

Faulting and Folding

Recent unpublished work by the author has established that there is no large-scale faulting in the Falkland Islands. The only fractures which have been detected in the Falklands are associated with folding in the competent Devonian quartzites. These faults are usually parallel to fold axes but compensatory transverse faults have been observed.

Hallé's (1912) " fault hypothesis " accounting for the presence of Falkland Sound has also been shown to be incorrect. Baker (1922), on the other hand, has gone no further than to state that there is insufficient evidence to support either theory, but nevertheless favours the " fold hypothesis " for the origin of Falkland Sound, by invoking a deep syncline between the two main islands.



TEXT-FIG. 3.—Map showing the suggested position of the Falkland Islands in relation to South Africa and South America in a reconstruction of Gondwanaland. Pecked line, limit of the Continental Shelf; dotted line, limit of the Karroo Basin; heavy broken line, Gondwanide Foldings; heavy dotted line, Brazilide and post-Nama Foldings; and, F. I., Falkland Islands.

An examination of Adie's (1952) geological map of the Falkland Islands reveals that the fold system in the East and West Falkland Devonian quartzites is continuous and not of two distinct ages as suggested by du Toit (1937, p. 119), who says " there are two main tectonic structures, the more important of which trends west to north-west, the other crossing it nearly at right angles ". In the light of recent evidence it is preferable to consider these fold-mountains, with their local flexure or loop, as being the eastward continuation of the " Cape Foldings " of South Africa, rather than occupying an intermediate position between the Cape Province and the Argentine. It then becomes immediately apparent that the Falkland fold-mountains are the counterpart of the Gondwanide Foldings of northern Argentina (see Map, du Toit, 1937, p. 27) which trend west-north-west to north-north-west.

Folding in the Devonian of the East Falklands is very close (cf. du Toit, 1937, p. 119), being almost isoclinal at the eastern end of the Wickham Heights, the east–west fold range. Similar folding has been observed in the Hornby Mountains, the north–south fold range of the West Falklands.

The " Falkland Foldings " are more closely comparable with those of the Caledon–Riversdale area than with the Ceres–Clanwilliam area of the Cape Fold belt.

Conclusion

From the above new evidence it is suggested that in future reconstructions of Gondwanaland the Falkland Islands should occupy a position some 250 kilometres east of the Eastern Province of South Africa as shown in Text-fig. 3.

Considering both the mode of disruption of Gondwanaland and the movements involved, which have been postulated by du Toit (1937) and King (1950), it is more reasonable to suppose that the Falkland Islands have travelled from the above-suggested position than from the position suggested by du Toit (1937). Under both hypotheses the distance of travel involved is similar.

It is hoped that the striking similarities between the Falkland Islands and the South African east coast recorded above will afford additional strength to the displacement hypothesis.

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Basic hornfels at a gabbro contact near Carlingford, Eire

By W. T. Harry

Abstract

Thermal metamorphism of Silurian sediments at a gabbro contact took place under pyroxene-hornfels facies conditions. The most common hornfels is essentially composed of pyroxene and labradorite ; its chemical composition compares with that of average gabbro. The hornfels is believed to have been metasomatically altered, probably basified, during metamorphism.

Field Occurrence

THE dominant geological feature of the Carlingford peninsula is a Tertiary igneous complex of which an important member is a large gabbro (eucrite) intrusion. The contact relationships between this intrusion and the surrounding Silurian grits and shales are unfortunately badly exposed. Traill (1878), however, writing of the Carlingford district, makes occasional brief reference to the contact alteration of Silurian sedimentary rocks occurring against the large basic igneous masses. He remarks (1878, p. 41) that " Near to the margin of the trap rocks the Silurian beds have been indurated, and at the higher elevations on Slieve Foye they are considerably metamorphosed, and resemble foliated metamorphic schists ".

The hornfels described in the present paper lies close to the gabbro on top of the prominent steep-sided spur referred to by Richey (1932, p. 105) in describing a vertical intrusive contact between eucrite and Silurian country rocks. The spur juts north-eastwards towards Carlingford Lough from Carlingford Mountain and lies a little over two miles north-west of Carlingford village. A small stream, the " Two Mile River ", follows the south-eastern side of the spur and runs to the sea. The course of the eucrite contact with Silurian sediments is, on top of the spur, marked by a small hollow running for about three hundred yards in a north-westerly direction. The eucrite here develops a marginal biotitic facies. On the north-eastern side of the hollow the Silurian sediments are hornfelsed. The exact locality is shown on Text-fig. 1. The hornfels is chiefly a banded, contorted rock, but at the south-eastern end of the exposures some massive non-banded types occur.

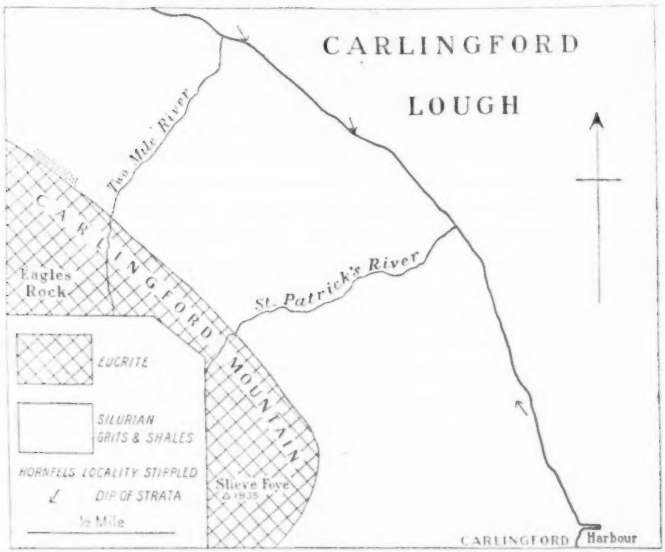
Petrography

As already remarked there are two types of hornfels apparent in hand-specimens. The commonest is a pale grey-coloured medium-grained rock of " stony " appearance and containing thin impersistent bands of coarser grain-size. The bands are aggregates of either dark green pyroxene or white feldspar. The second type of hornfels

is medium- or fine-grained, dark in colour and massive, without banding.

Nineteen thin-sections were examined and two hornfels varieties were distinguished microscopically. Generally, although not invariably, these correspond to the two hand-specimen types. In thin-section nearly all the pale banded hornfels is a pyroxene-labradorite rock, and most of the dark massive hornfels is essentially composed of pyroxene, labradorite, and potash-feldspar.

Pyroxene-labradorite hornfels (Text-fig. 2A).—The texture is granoblastic and of fine to medium grain-size. The relative amount of



TEXT-FIG. 1.—Sketch map of the Carlingford neighbourhood showing the hornfels locality.

pyroxene and labradorite often changes considerably within individual hand-specimens. For this reason the modal composition of the analysed specimen (Table I) was not determined geometrically from thin sections. The specimen consisted of pyroxene and labradorite usually in subequal amounts but sometimes concentrated in monomineralic lenses. The pyroxene forms granules or prisms faintly coloured green or brown. It is optically positive and monoclinic; polysynthetic twinning and feeble pleochroism sometimes occur. Usually the mineral is fresh. Often it contains a fine parting of an opaque substance. In one specimen this clinopyroxene was

associated with some extremely poikiloblastic microporphyroblasts of hypersthene.

The labradorite is fresh, unzoned, with well-developed albite twinning. Accessory minerals that may be present are iron-ore grains, quartz, and (rarely) a foxy-red "hornfels" biotite. Two olivine crystals were identified in one thin-section. Occasionally the rock is traversed by microscopic veinlets of fibrous green amphibole and chlorite.

Pyroxene-labradorite-potash-feldspar hornfels.—This also has a granulitic "hornfels" texture. It is fine- or medium-grained. The

TABLE I

	1	A	B
SiO_2	49·22	50·16	48·24
TiO_2	0·26	0·70	0·97
Al_2O_3	18·63	15·70	17·88
Fe_2O_3	0·46	1·83	3·16
FeO	5·50	4·98	5·95
MnO	0·15	—	0·13
MgO	9·52	9·04	7·51
CaO	14·87	15·96	10·99
Na_2O	0·68	1·52	2·55
K_2O	0·21	0·02	0·89
H_2O+	0·62	0·24	1·45
H_2O-	0·18	nil	
CO_2	nil	—	—
P_2O_5	traces	—	0·28
	100·30	100·15	100·00

1. Pyroxene-labradorite hornfels, Carlingford, Eire. Anal. Herdsman. (See text.) Niggli values : al 23, fm 41, c 34, alk 2.

A. Hornfels inclusion in gabbro. The inclusion, originally slate, has been altered to gabbroic composition. F. F. Grout, 1933. *Bull. Geol. Soc. Amer.*, xliv, p. 1017.

B. Average composition of 41 gabbros. R. A. Daly, 1933. *Igneous Rocks and the Depths of the Earth*, p. 17.

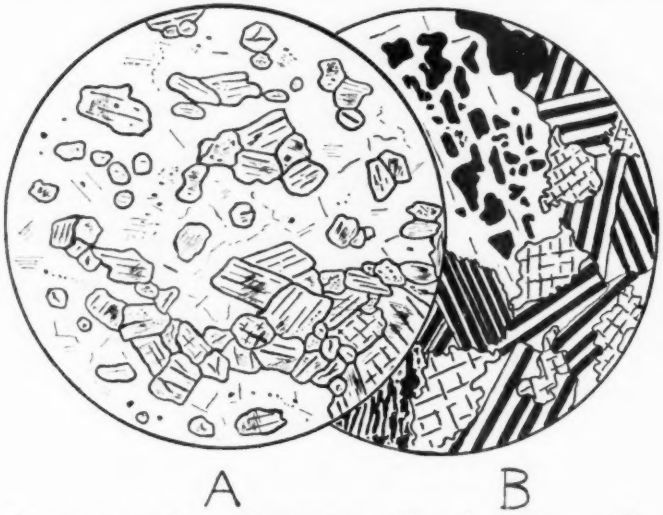
mineral components occur in variable proportions. A faintly brown-coloured optically positive clinopyroxene with maximum interference colours of the middle second order forms small crystals in a colourless, chiefly feldspathic base. The latter, which constitutes most of the rock, consists of labradorite prisms in a poikiloblastic matrix of potash-feldspar. Quartz may either form crystal individuals or occur in micrographic intergrowth with potash-feldspar. Such micropegmatite tends to be concentrated within a few small patches in the thin sections in which it occurs (Text-fig. 2B).

Common accessory constituents are foxy-red biotite as very spongy

plates, small grains of iron-ore, and rutile needles, the last usually being set in potash feldspar.

Petrogenesis

The field relationships, mineral composition, "hornfels" texture, lack of zoned crystals and megascopic appearance of the rocks described all indicate a thermal metamorphic origin due to the eucrite intrusion. The hornfels originally may have been either Silurian sediment or, it may possibly be suggested, an early chilled marginal phase of the eucrite. The latter possibility may readily be dismissed for several



Text-fig. 2.—A. Pyroxene-labradorite hornfels, ordinary light. × 100. B. Pyroxene-labradorite-potash feldspar hornfels, crossed nicols. × 50. Micropegmatite (top and bottom left) pyroxene (crossed lines), quartz (black), labradorite.

reasons. The boundary of the hornfels outcrop swings outwards, away from the general course of the eucrite boundary, into an area that would from general mapping be expected to be Silurian. The hornfels is commonly banded but chilled edges of igneous rocks are seldom so constituted. Some hornfels specimens contain abundant potash-feldspar whilst the eucrite does not. Finally, hand-specimens of the hornfels immediately suggest by their appearance an altered sediment rather than a metamorphosed igneous rock. The Carlingford hornfels may be ascribed to thermal metamorphism of Silurian sedimentary rocks. It can be referred to the pyroxene-hornfels metamorphic facies of Eskola from its two-pyroxene mineral association

with labradorite and from comparison with rocks in contact aureoles characteristic of that facies. Thermal aureoles around gabbro intrusions almost invariably include hornfels belonging to the pyroxene-hornfels facies.

An important problem presented by the Carlingford hornfels is whether its metamorphism was isochemical or accompanied by change in the bulk composition of the rock. The problem arises from the following facts. The Silurian country-rocks are grits and shales ; these obviously will be markedly dissimilar to the analysed hornfels in chemical composition. Furthermore the chemical composition of the hornfels is abnormal for a sedimentary rock. As often remarked, chemical analyses of sedimentary rocks show a general tendency for MgO, K_2O, and Fe_2O_3 to exceed CaO, Na_2O, and FeO respectively. None of these features is shown by the Carlingford hornfels. The Carlingford rock neither compares with any of Stoke's composite samples of shales, sandstones, and limestones (Clarke, 1924, p. 30), nor any mixtures of those samples. It is not comparable with any of the analyses of sedimentary rocks quoted by Pettijohn (1949). Niggli (1950) has collected chemical analyses of many hornfelses and other metamorphic rocks and also of some sediments, but only one, a schistose amphibolite of uncertain origin is at all comparable chemically with the Carlingford rock. The latter does, however, bear much similarity to Daly's average composition of forty-one gabbros, quoted in Table I.

The chance occurrence at a gabbro contact of a small patch of metamorphosed sediment originally of an unusual gabbroic chemical composition but stratigraphically part of a large surrounding area of grit and shale is not very probable. It appears more likely that the hornfels was metasomatically modified during metamorphism by the gabbro. The hornfels and gabbro both formed under similar P–T conditions. Whilst making the hornfels the gabbro seems also to have supplied those elements necessary for the hornfels to assume a mineral composition like that of the gabbro. Grout (1933, p. 1021) comments : " Gabbro hornfelses resemble gabbro, whatever their origin." Transfer of material from the eucrite was helped perhaps by the veining of Silurian contact rocks by eucrite which has been observed at the Carlingford hornfels locality.

Because the original composition of the hornfels is not known the chemical changes during metasomatism cannot be accurately assessed. However, since the Silurian country-rocks are chiefly grit and shale the composition of the hornfels most probably was similar. In such a case the metasomatism would have been a " basification " like that postulated at certain gabbro contacts by several workers, including Grout (1933, pp. 1008–1040) and, recently, Sadashivaiah (1950).

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Limestone Blocks in the Lower Cretaceous Cuche Formation of the Central Range, Trinidad, B.W.I.[1]

By K. W. Barr

Abstract

The occurrence of large blocks of fossiliferous Cretaceous limestone among the Lower Cretaceous shales of the Central Range area of Trinidad, B.W.I., has been known for many years, and several different modes of origin have been advanced. A critical exposure which shows the field relationships between the shales and limestone blocks is described, from which it is concluded that the limestone blocks were derived from the contemporaneous breaking up of limestone reefs, and the inclusion of such blocks, together with fore-reef breccia, in the adjacent shale deposits.

I. Introduction

FROM the earliest surveys of Wall & Sawkins (1860) the occurrence of large blocks of fossiliferous limestone occurring among the older Cretaceous shales of the Central Range has attracted the attention of geologists. Wall & Sawkins described the so-called " Stack Rock limestone " which occurs just offshore at Pointe-a-Pierre at the western end of the Central Range, from which they collected a few unidentifiable fossils. They also noted the occurrence of similar limestones from the Mount Harris area in the eastern part of the island.

During the years 1920 to 1924 the Central Range area was subjected to a good deal of attention and numerous fossiliferous limestone localities were discovered. Conspicuous among the fossils found were a number of rudistiform types which were described by Harris & Hodson (1922) ; whilst some other Cretaceous forms from Pointe-a-Pierre were described by Bullen-Newton (1924). In age, these were considered to range from Neocomian to Albian, and possibly even to Cenomanian.

Waring (1926, p. 38) describes these limestones as " lenticular masses of hard, dark grey, compact limestone that carry molluscan fossils, largely replaced by calcite " occurring in the Lower Cretaceous shales. In the same publication, Harris included a note on the rudistids of the Stack Rock and Plum Road localities (op. cit., p. 95). Liddle (1928, p. 436) grouped these isolated limestones together as the " Plum Road Formation " of Lower Cretaceous (Albian-Aptian) age, and was of the opinion that the surrounding, often contorted shales were of Upper Cretaceous age, through which the limestone blocks had been faulted or squeezed. The shales were thus assumed to be younger than the limestones, a conclusion which was based on a comparison

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with the Cretaceous rocks of Eastern Venezuela, the limestones themselves being considered equivalent to the El Cantil formation (Albian-Aptian). As no fossils were known from the shales, this supposition could not be established beyond doubt. In the revised version of his book (Liddle, 1946, p. 703) the same views are maintained.

Kugler (1936) noted the occurrence of these limestone masses and compared them to the Cogollo (El Cantil) limestone of Venezuela. On the basis of the caprinids and other rudistids, he considered them to be of Cenomanian age, but the origin of the limestones was not discussed.

Hutchison (1938) stressed the block-like character of the limestones, and their frequently large size, roughly cubical masses up to 20 feet across having been observed. He noted that contacts are rarely exposed but the adjacent shales are often contorted. He considered that they were not erratics but had originated from the breaking off of blocks from a limestone reef, and the settling of such blocks in the adjacent muds and sands. As a result, he concluded that the limestone blocks and surrounding shales are essentially contemporaneous, and the fossils from the limestone can be used to date the shales.

During the course of field work in some of the Cretaceous areas of the Central Fange, the writer was able to re-examine the Cuche River section and to reach certain conclusions as to the origin of these limestone masses.

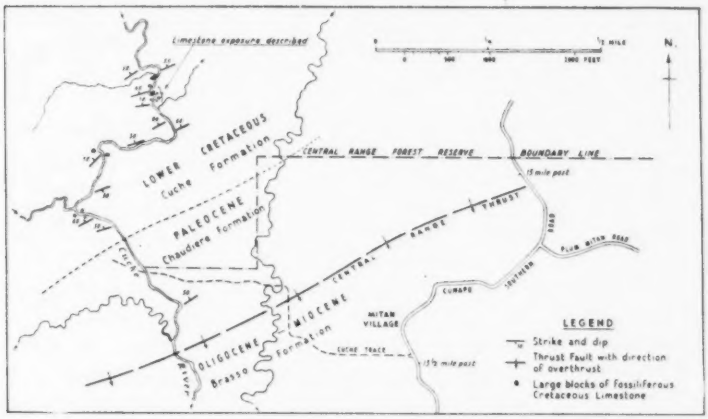
II. General Statement

Large blocks of fossiliferous limestone occur among the shales of the Lower Cretaceous Cuche formation of the Central Range. They are found most commonly east and west of Mt. Harris in the eastern part of the Central Range, where the exposure of the Lower Cretaceous attains its maximum development. They are particularly plentiful in the vicinity of Plum Road and along the several branches of the Cuche River. The general characteristics of these limestones are that they consist of dense, medium to light grey limestone, sometimes with abundant calcite veins and often fossiliferous, and which would generally be described as a bioherm type of limestone. They occur as block-like masses commonly from 4 to 10 feet across, but sometimes much larger, when they form roughly cubical masses up to 20 feet across which stand as conspicuous knolls on the hill-sides or beside the stream courses. They show ragged or fluted weathering, and are sometimes fantastically sculptured by solutions channels. They are associated with dark shales of the Cuche formation ; the contact relationships are rarely displayed, but the nearby shales are sometimes contorted. The limestones are generally massive, but

where bedding is discernible the dip and strike bear no relation to the regional trends. Molluscan fossils predominate, with rudistids and oysters as the more commonly occurring forms; other bivalves, gastropods, and algae are also found, whilst corals are decidedly rare.

III. The Cuche River Section

The critical section lies in the upper reaches of the Cuche River approximately three-quarters of a mile west of the 13 mile post on the Cunapo Southern Road; the locality is shown in Text-fig. 1. From south to north the river exposures show a sequence of steeply dipping

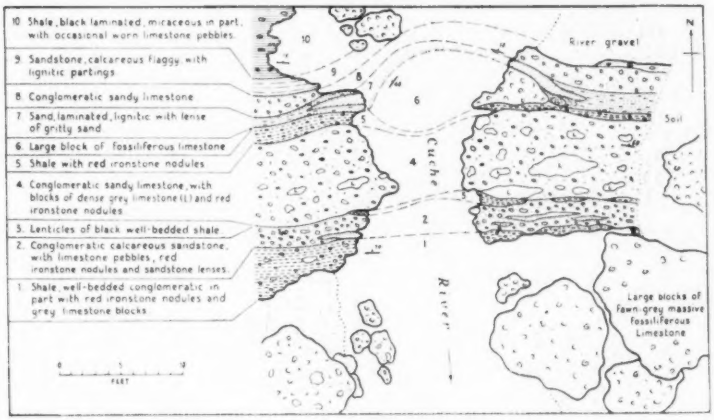


TEXT-FIG. 1.—Sketch map showing the Cuche River Limestone Locality.

black shales, usually rather silty, well laminated, and often showing conspicuous detrital mica flakes along the bedding planes. From time to time inconstant bands of scattered red limonitic claystone nodules ($\frac{1}{2}$ in. to 2 in. across) occur among the shales. There are also occasional bands from 2 in. to 6 in. thick of "lustre-mottled" calcareous quartzite, in which the "lustre-mottled" effect, which is seen on cross-fracture, is due to the crystallization of hypidiomorphic calcite crystals from $\frac{1}{4}$ in. to $\frac{1}{2}$ in. across which poikilitically enclose the quartz grains. Occasional medium-sized blocks (3–6 feet diameter) of dense grey limestone, sometimes fossiliferous, occur in the stream course or along the banks but these are probably not in situ.

The crucial exposure occurs approximately 700 yards north of the point at which the Forest Reserve boundary line intersects the river, and here may be seen the association of the large limestone blocks and

the dark shales of the Cuche Formation. At the southern end of the section are exposed northward dipping, steeply inclined, black shales with occasional red ironstone nodules. Then come several large blocks of dense grey fossiliferous limestone 10 to 15 feet across with fragments of *Ostrea* and echinoids ; these are surrounded by alluvium and no contact with the shales is exposed. Immediately upstream a rib of solid formation crosses the river forming a small waterfall, and this shows a sequence of conglomeratic shales, conglomeratic sandy


10. Shale, black laminated, micaceous in part, with occasional worn limestone pebbles.
9. Sandstone, calcareous flaggy with lignitic partings.
8. Conglomeratic sandy limestone.
7. Sand, laminated, lignitic with lense of gritty sand.
6. Large block of fossiliferous limestone.
5. Shale with red ironstone nodules.
4. Conglomeratic sandy limestone, with blocks of dense grey limestone (L) and red ironstone nodules.
3. Lenticles of black well-bedded shale.
2. Conglomeratic calcareous sandstone, with limestone pebbles, red ironstone nodules and sandstone lenses.
1. Shale, well-bedded conglomeratic in part with red ironstone nodules and grey limestone blocks.
FEET
River gravel
Soil
Cuche
River
Large blocks of fawn-grey massive fossiliferous Limestone
N

TEXT-FIG. 2.—Sketch map of Limestone Exposure in Cuche River.

limestone with large limestone components, followed by shale and sandstone bands which include a large inbedded block of limestone. Both the conglomeratic shales and sandy limestone contain numerous deep red clay-ironstone nodules. The sequence is shown in detail in Text-fig. 2 in which the beds are numbered from 1 to 10 from south to north ; as the dip is steep (60°–70°) this is virtually a true strike section. A cross section of the sequence is shown in Text-fig. 3.

The lithologic sequence is described below :—

	Thickness.	*Lithology.*
Bed 1.	5 ft. minimum .	Conglomeratic shale, black, poorly bedded, micaceous, with abundant red ironstone nodules and rare rounded pebbles of dense grey limestone. This forms part of several hundred feet of shale lying south of the limestone section.
Bed 2.	2 ft. 6 in. . .	Conglomeratic, calcareous sandstone, medium to coarse grade, with sub-rounded pebbles of dense grey limestone up to 3 in. across, and occasional red ironstone nodules.

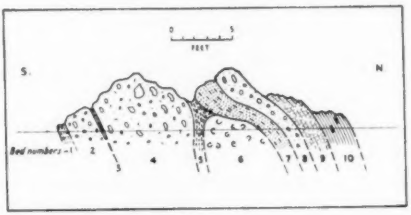
Bed 3.	0 to 1 ft. 3 in. .	Lenticular shale, black, well-bedded.
Bed 4.	7 ft. to 9 ft. .	Conglomeratic, sandy limestone with red ironstone nodules, pebbles, and lens-shaped blocks up to 3 ft. long of dense grey limestone.
Bed 5.	6 in. to 1 ft. .	Shale, black, poorly bedded with scattered red ironstone nodules.
Bed 6.	Up to 6 ft. 6 in. .	Limestone boulder (12 by 6½ ft.) of dense grey fossiliferous limestone, with algae, echinoid, and bivalve fragments.
Bed 7.	1 ft. 6 in. to 2 ft.	Sand, brown, laminated with occasional lignitic partings, including a lens of brown, coarse, gritty sand.
Bed 8.	2 ft. to 3 ft. .	Conglomeratic sandy limestone with fragments of dense grey limestone and red ironstone nodules.
Bed 9.	1 ft. 6 in. to 2 ft.	Calcareous sand, brown, micaceous, well bedded to flaggy.
Bed 10.	10 ft. minimum	Shale, black, micaceous in part, laminated to well bedded with occasonal pebbles of worn grey limestone ½ in. to 6 in. across.

The limestone components of bed 4 are water worn, more or less lens-shaped, blocks 6 inches to 3 feet across, of dense grey limestone similar in appearance to the large blocks lying to the south. Particular interest centres upon the block of limestone, bed 6, which is a large water-worn block of dense grey fossiliferous limestone full of broken shell fragments and algal remains, and measuring 12 feet by 6½ feet. To the south it is in contact with black laminated shale (bed 5) with ironstone nodules, and careful removal of the shale at this contact shows a smooth water-worn surface with cross-sections of fossils, so that clearly the limestone was a worn boulder at the time of its incorporation in the shales and not a bioherm in position of growth.

On the upstream side the limestone block is in contact with a brown gritty sandstone (bed 7) with occasional thin partings of carbonaceous matter approaching lignite. This sandstone follows the shape of the limestone block, but on the east side lenses out rapidly into a well-bedded micaceous sandstone with lignitic partings. Where bed 7 comes against the edge of the limestone block on the eastern side there is local contortion as if the sand had been ploughed up and overturned, and included in this disturbed sand is a lenticle of coal 1 inch thick. The sands of bed 7 are followed by another layer of conglomeratic sandy limestone (bed 8), then by laminated sandstone (bed 9) and finally by the typical black laminated Cuche shale (bed 10) which, however, also contain a few scattered, worn fragments of grey limestone sometimes measuring up to 6 inches across. Some small-scale, irregular contortion due to slumping is also present in these shales.

The limestone boulder (bed 6) appears to be a large slipped block, the upper part of which has been exposed by erosion. The sandstone layer

(bed 7) shows a decrease in dip to 40° in the stream bed demonstrating that the block increases in size below the present surface (see Text-fig. 3). The fact that this sandstone follows around the curved surface of the block suggests that it may be in fact the original basal deposit which has been down-warped by the weight of the boulder ; the shales (bed 5) would then have been deposited across the almost level surface of limestone and surrounding sand. The contortion noted in the sands east of the limestone may have been caused by the sinking of the block into the sands, but elsewhere the sands do not appear to have been much disturbed. If this interpretation is accepted, it would follow that the beds to the north are the older, and since the dip is steadily



TEXT-FIG. 3.—Sketch of west side of Limestone Exposure, Cuche River.

northward, the sequence would then be steeply overturned. Some confirmatory evidence for the relative order of the beds is shown at the contact of beds 3 and 4, when the thin and discontinuous shales of bed 3 appear to rest on an eroded surface of bed 4. As the area is one of strong tectonics associated with major thrusting, the possibility of local inversion of the beds would not be an unreasonable conclusion. Apart from some minor local contortion clearly referable to slumping there is no evidence of abnormal tectonic conditions within the shale-limestone complex.

The components of the conglomeratic beds consist mainly of dense grey limestone, usually unfossiliferous, but sometimes with molluscan and algal remains, and generally similar in lithology to the larger limestone blocks. In addition there are red clay-ironstone nodules exactly similar to those occurring in the Cuche shales, and rare fragments of brown quartzitic sandstone which can also be matched within the Cuche formation. No fossils have been found to suggest that the deposits are polygenetic. The conglomeratic beds, including the large limestone blocks, lie within the Cuche formation and are clearly part of the depositional sequence ; they are essentially intra-formational conglomerates and could be considered as representing a fore-reef facies deposit in which reef detritus has been incorporated in the adjacent muds.

Although no contacts with the Cuche shales have been seen in the case of the large limestone blocks south of this exposure, nor in the case of the even larger blocks occurring upstream to the north (Text-fig. 1), it is inferred that they are in fact similar in occurrence to the limestone block complex here described.

IV. The Origin of the Limestone Blocks

Three possible origins for such limestone blocks have been suggested at various times : (*a*) that they are derived from an older limestone deposit undergoing erosion, or, (*b*) as Hutchison (1938) suggested, that they are derived from the contemporaneous breaking up of limestone reefs and the slipping of the detritus into the adjacent muds ; or (*c*), according to Liddle (1928 & 1946) that they are tectonic enclaves torn off from the underlying formations and thrust up along the younger shales.

Taking the latter suggestion first, it is clear from the foregoing description that the limestone and associated conglomeratic beds are interbedded in the shales among which they occur, and that there are no abnormal tectonic features such as would be expected had the limestone been thrust into the shales. The idea of a tectonic origin may therefore be dismissed as untenable.

The field evidence clearly indicates a sedimentary mode of origin, and at this point the relative ages of the limestone and enclosing shales need to be considered. There is no critical palaeontological evidence in the section here described as the shales are unfossiliferous and the limestone blocks carry only facies fossils. However, if the bulk of the evidence from such limestone blocks throughout the Central Range is considered (Liddle, 1946), a rich and varied fauna has been found, including many types of rudistids which are considered to range in age from Neocomian to Albian or even to Cenomanian (Harris & Hodson, 1922). There seems no reason to assume, as did Renz (1942), an exclusively Cenomaian age, as in the original determination emphasis was placed on a somewhat earlier age. Again, based on evidence from the whole of the Central Range, the Cuche formation is now considered, on the basis of the foraminiferal fauna, to be mainly Barremian in age (Bronnimann, P., 1951—private communication).

It is therefore evident that there is essentially no significant difference in age between the Cuche shales and the limestone blocks. Certainly, the limestones cannot be Cenomanian, that is, younger than the enclosing shales because of the field relationships ; nor does it appear that they can be sufficiently older than the shales as to support the idea that they are derived from a pre-existing formation, either by normal erosion, or by tectonic derivation. It is therefore concluded that the explanation put forward by Hutchison (1938) is the most acceptable.

namely, that the limestone blocks are derived from the penecontemporaneous break-up of limestone reefs and the incorporation of such reef fragments into the fore-reef deposits, with the consequence that the limestones and the enclosing shales are essentially of the same age.

A somewhat similar process, but in this case under sub-aerial conditions, which by analogy serves to illustrate the mode of origin of the limestone masses, can be seen taking place at the present day on the east coast of Barbados in the vicinity of the village of Bathsheba. This village lies on the coast, and inland the ground rises steadily towards the sheer bluff of Hackleton's Cliff some mile and a quarter away, which reaches an elevation of over 900 feet. Hackelton's Cliff is formed of some 250 feet of Coral Rock, a young uplifted reef limestone deposit which caps the greater part of Barbados, whilst the sloping ground descending toward the shore is formed of marls, clays, and shales of the Oceanics and underlying Scotland formations (Schuchert, 1935). Due to seasonal landslip or strong headward erosion of the streams, large blocks of Coral Rock are broken off from the cliff, and these gradually make their way slipping down the plastic clay-marl slopes towards the sea. The limestone blocks, which are sometimes as large as a house, can be seen in all stages of their downward journey from the foot of Hackleton's Cliff to their final resting place on the foreshore. The operation of a similar process involving a living reef under submarine conditions appears entirely feasible.

Taken as a whole, the Cuche formation consists of a thick series of dark shales of 2,000 feet minimum and perhaps amounting to as much as 5,000 feet in thickness, with subordinate quartzose sands and conglomeratic limestones such as here described, but no extensive limestone beds are known to occur in the entire Central Range area. The dominant rock type is shale and an open water marine environment is indicated, not necessarily of great depth, but probably beyond the neritic zone. No reef limestones are known in situ in the Lower Cretaceous of Trinidad, with the exception of the small reefs at Toco at the eastern end of the Northern Range described by Trechmann (1935), which is some 20 miles away. It may therefore be necessary to assume that the limestone blocks and associated limestone reef detritus have travelled some distance from their point of origin to their final resting place in the shales of the Central Range area. This does not appear to involve any particular difficulty as it is apparent that detached blocks can travel long distances down submarine slopes, perhaps assisted by wholesale slumping. Moreover, Kuenen (1950) has shown that the activity of turbidity currents of high density can carry coarse deposits great distances.

It is therefore concluded that the Lower Cretaceous limestone block

complexes of the Cuche river type originated in the breaking off of blocks from the outer edges of limestone reefs, and the slipping of the blocks together with fore-reef detritus down the fore-reef slopes—perhaps assisted in their journey by slumping or by turbidity currents—into the deeper water shale environment where they were ultimately buried. In this way limestone blocks simulating erratics may be imbedded in shales which are geologically not significantly younger than the limestones themselves.

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POINTE-A-PIERRE,
TRINIDAD, B.W.I.

The Great Glen Crush-Belt

By V. A. Eyles and A. G. MacGregor *

Abstract

This paper provides field and petrographic evidence believed by the authors to indicate that the Great Glen, over a lateral distance of some 40 miles between Fort William and Foyers, is flanked on the south-east by a broad crush-belt characterized by intense cataclasis and localized mylonitization. Most of the detailed evidence has not previously been published.

I. Loch Lochy–Loch Oich Area: Field Evidence

(By V. A. Eyles)

DR. S. J. SHAND (1951, pp. 423, 427) claims to have shown that " mylonite is extremely rare in the plane of the Great Glen Fault ", and that if " the few trivial occurrences " that have come to his notice " were multiplied a thousandfold they would still fall far short of the requirements of Kennedy's hypothesis and of his claim that there is in the Great Glen ' a broad belt of crushed, sheared, and mylonitized rock up to about a mile in width ' " (Kennedy, 1946, p. 45). Dr. Shand's scepticism regarding this broad belt of crushed, sheared, and mylonitized rock is not shared either by me or by present or former Geological Survey colleagues who have had occasion to study the Great Glen. It therefore seems desirable to record in more detail the evidence on which Professor Kennedy's statement was based.

The following circumstances led to the collection of much of this evidence. In 1935 the Research Department of the Forestry Commission requested the Geological Survey to report on the lithological nature of the rocks in an afforested area, some two miles long and up to half a mile broad, bordering the south-east side of the Great Glen, adjacent to the north end of Loch Lochy and ten miles south-west of Fort Augustus. This area had not been mapped by the Geological Survey, but the presence in it of Old Red Sandstone sediments (shown on Geikie's 10 mile-to-the-inch geological map of Scotland) had long been known.

I was detailed to carry out a rapid investigation. Afforestation on the very steep slopes leading up from the Glen, as well as the presence of drift deposits, made examination of the area difficult. Fortunately the south-east side of the Glen in the area concerned is dissected by several large streams that cut transversely across the general north-easterly strike of the bedded rocks, affording more or less continuous exposures. In addition other easily accessible outcrops were available beside the old railway line that runs along the foot of the slope.

It was found that in the belt under examination there were present, in addition to obvious Old Red Sandstone sediments, rocks of varied

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types, including schistose beds of unusual character that were clearly not normal Moine Schists of the type that are met with in bulk to the north-west and south-east of the Great Glen. Taken as a whole, apart from the Old Red Sandstone sediments, the rocks did not recall those of any Scottish formation with which I was familiar.

Systematic mapping of the area was impossible in the time at my disposal, but seven sections in streams that enter the Glen from the east were examined. In one of these, Allt an Lagain, there were more or less continuous exposures of rock for a distance of about one mile. The information derived from these stream sections and from a few traverses into the surrounding country made it possible to establish that, over a lateral distance of at least four miles on the south-east side of the Great Glen, the bordering rocks may be divided into three zones, here designated *A*, *B*, and *C*. These zones are elongated from north-east to south-west, that is, in the same general direction as the Glen itself. Within the area examined there is no doubt as to the existence and approximate limits of the zones, though further examination might modify their boundaries in detail. In particular, it might prove possible to relate them more closely to the general pattern of faulting and the crush lines that were observed. Subsequent petrographic examination showed that Zones *A* and *C* are characterized by severe cataclastic effects, which are clearly related, respectively, to the Great Glen Fault and to another large fault, the Glenbuck Fault, that runs in a direction apparently slightly oblique to the Great Glen.

Zone *A*, adjacent to the Great Glen, can be shown to extend for four and a half miles from the head of Loch Lochy north-eastwards, with a maximum width of about 650 yards near the south-west end of Loch Oich, though apparently narrowing both to the north-east and to the south-west. Petrographic examination of the specimens collected from this zone has shown it to contain highly sheared and crushed igneous rocks of Caledonian types, locally associated with Old Red Sandstone sediments, as well as schistose rocks apparently developed by mylonitization of Old Red sediments, and also some rocks that were possibly originally gneisses (p. 432). Owing to the prevalent crushing it is a matter of great difficulty to determine the original relationship between the different rocks in this Zone. However, a highly crushed dioritic rock (31574) [1] occurs in contact with a coarse pink granite (not sliced) at the south end of Creag nan Gobhar, north of Allt an Lagain, in a part of Zone *A* where neighbouring exposures consist largely of Old Red Sandstone sediments (and in Zone *B*, described below, coarse pegmatite cuts Old Red Sandstone). The evidence, therefore, so far as it goes, suggests that the igneous rocks,

[1] Numbers in brackets refer to rock slices in the Scottish collection of H.M. Geological Survey.

or some of them, cut Old Red Sandstone; but apart from the pegmatites (p. 429) this is not yet certain.

Zone *B*, east of Zone *A*, is about half a mile wide opposite the south end of Loch Oich, but narrows somewhat towards the south-west and possibly broadens considerably towards the north-east. It consists almost entirely of flagstones and conglomerates of Old Red Sandstone type, for the most part not obviously crushed; and, though obvious crush lines occur within the zone, the original nature of the rocks was never in doubt.

Zone *C*, to the east of Zone *B*, is marked by the presence of schistose rocks some of which are similar to those occurring within Zone *A*, and are believed by Dr. MacGregor and by me to have been formed from Old Red Sandstone sediments. The broad belt of Old Red Sandstone rocks within Zone *B*, and also the schistose rocks just referred to, dip south-east and must therefore be separated from Moine schists to the east by a major fault, almost certainly the fault that determines the line of Glen Buck, which must extend south-westwards from the head of this Glen in a direction nearly parallel to the Great Glen Fault. It was not possible to determine the precise position of the Glen Buck Fault within or adjacent to the area examined for the Forestry Commission, partly on account of limitation of time, and partly because the high ground which it traverses is often obscured by superficial deposits. Also included among the rocks that have been assigned to Zone *C* are highly sheared igneous types, sheared limestone, and carbonate rock of doubtful origin, and practically uncrushed garnetiferous semi-psammitic schist (31534–8). These latter rocks, in part at least, are probably Moine Schists, and must occupy a position east of the Glen Buck Fault. It has been shown by subsequent petrographic examination that shearing and cataclasis are, on the whole, about as severe in Zone *C* as in Zone *A*. Zone *C*, therefore, is a zone of sheared and crushed rocks broadly speaking similar in character to those in Zone *A*, that appears to be directly related to a subsidiary fault, the Glen Buck Fault, about one mile to the south-east of the Great Glen Fault. Two practically unsheared and uncrushed metamorphic rocks of Moine type (31539, 31540) collected rather more than a quarter of a mile south-east of the specimens just mentioned most probably lie outside Zone *C* of the crush belt, which however is, at least locally, 400 yards wide.

While the true nature of many of the rocks occurring in Zones *A* and *C* was not established until after they had been sliced, an igneous origin was strongly suspected for certain of the types in Zone A. In general, a low grade of metamorphism was suggested by the prevalence of chlorite and calcite. Thin chlorite-quartz veins (p. 433) were found in all three zones. The fact that the rocks in Zones *A*

and *C* had been involved in much crushing was emphasized by the presence of (*a*) a number of definite crush-lines ; and (*b*) conglomerates (e.g. 31565 from Zone *A*) which though obviously severely crushed and sheared, were still recognizable as such, though differing greatly in appearance from the apparently uncrushed Old Red Sandstone conglomerates in Zone *B*. The crushed conglomerate in Zone *A*, just referred to, forms an easily accessible exposure at the point where the Allt an t-Sithein passes under the railway, about half-way between Lochs Lochy and Oich, and 350 yards south of South Laggan. An impression that the crushing in Zone *A* might be very severe was given by the discovery of small dark veinlets strongly resembling the flinty-crush rock in the Lewisian rocks of Coll and Tiree, with which I was familiar, though the Great Glen veins were thin, inconspicuous, and of infrequent occurrence.[1]

A commonly occurring type in Zones *A* and *C* is a hard dark-grey, very compact, somewhat phyllitic-looking rock that frequently contains pale siliceous nodules varying from a fraction of an inch up to several inches in diameter (p. 433). These rocks form bands several feet thick, conformable to the general strike. Microscopic examination has indicated that they are ultramylonites with small relics of uncrushed rock and mineral fragments ; and that they have been developed, in different instances, by intense shearing of Old Red Sandstone sediments and of igneous rocks (p. 432). Easily accessible exposures of these mylonites are to be seen at the side of the old railway, roughly two miles north-east of South Laggan, on the east side of Loch Oich (31792, 33630).

A large number of specimens was collected from the area as a whole, and some eighty were subsequently sliced. Of these, forty-four come from Zone *A* and are representative of its varied rock types. Only twelve specimens from Zone *B* were sliced, because in this zone the rocks are almost entirely recognizable Old Red Sandstone sediments ; these sliced specimens include two examples of quartz-chlorite veinlets (p. 433) and a coarse muscovite-pegmatite.[2] The twenty-one sliced-specimens from Zone *C* are probably not fully representative of the zone, but they are sufficient to indicate that Zones *A* and *C* are in a

[1] See p. 432 for a description of the microscopic character of the specimen sliced (31547).

[2] Coarse pegmatites of thoroughly igneous type, often several feet thick, cut rocks of Zone A, as well as the easily recognizable Old Red Sandstone sediments of Zone B. Professor Kennedy (1946, p. 45) says : " small segregation pegmatites have been developed even in the crushed and foliated sandstones " in this area " as a result of the deformation ". It must be presumed he refers to the thin quartz-chlorite veins, and not to coarse muscovite-pegmatites, of which several examples were noted (e.g. 33620). The quartz-chlorite veinlets are mentioned by Dr. MacGregor in his petrographic notes (p. 433).

similar cataclastic condition, and that both include Old Red Sandstone sediments.

In 1936, a selection of these slices was submitted to Professor H. H. Read, who had been studying highly sheared rocks in Shetland. Professor Read sent me a letter at the time, in which he gave his preliminary conclusions. With his permission, I quote the following extract :—

> " Almost all the rocks . . . are affected by extreme epi-metamorphism . . . with characteristic minerals chlorite, calcite and sericite . . . There are some very beautiful cataclastic structures . . . There are several examples of almost flinty crush . . . Altogether it seems to me you have a belt of thorough cataclastic metamorphism about 1 to 1½ miles in width from the Great Glen Fault, which is superimposed on (1) a higher grade general Moine metamorphism and (2) on non-metamorphic O.R.S."

The slices were also seen by Professor Kennedy at about the same time, when he was preparing his paper on the Great Glen Fault. There was then no doubt in the minds of those who discussed the problems involved that Professor Kennedy would be justified in stating that there exists adjacent to the Great Glen a belt of crushed, sheared, and mylonitized rocks up to about a mile in width, extending from the north end of Loch Lochy to the south end of Loch Oich.

That was the position in 1936. Since the war, Dr. A. G. MacGregor, in connection with his current work as District Geologist for the Scottish Highlands has made a detailed, systematic, and entirely independent examination of all the rock slices and of the corresponding hand specimens. His general conclusions agree with those arrived at in 1936 by Professor Read, by Professor Kennedy, and by myself.

Dr. MacGregor has supplied me with statistical details of the cataclastic phenomena which may be tabulated as follows :—

TABLE SHOWING ZONAL DISTRIBUTION OF CATACLASIS *

	Zone A	Zone B	Zone C	Total
Mylonite. . . .	4	—	5	9
Semi-mylonite . .	10	1	5	16
Highly sheared and/or crushed.	18	4	7	29
Somewhat sheared and/or crushed.	11	4	2	17
Practically uncrushed .	1	3	2	6
Total . . .	44	12	21	77

* Four slices are omitted from this table (see p. 431, footnote).

Rather more than half the specimens tabulated above come from Zone *A* ; these were selected originally, not to exemplify the incidence of cataclasis, but to represent the various lithological types of the zone. The Zone *C* specimens were selected with the same end in view. The single specimen from Zone *A* classified as " practically uncrushed " (31558) is a small residual kernel of biotitic hornblendite contained in a 25-ft. bed of rock recorded in the field as a " soft mica-schist " and subsequently recognized to be of mixed igneous origin (sheared basic hornblende-biotite-rock, and sheared hornblende-biotite-diorite, 31556, 31557).

A practically uncrushed Zone *C* rock is an acid plagioclase porphyry (31526) that was found not far from mylonitized and semi-mylonitized sediments (31527–8, 33626–7).

Three rocks collected from the intermediate Zone *B* are little affected by crushing and shearing, although highly sheared rocks occur in close proximity. Two of these are practically normal fine-grained sandstones of Old Red type (31650, 33628). The third (31783) is somewhat affected by general shearing, and in Dr. MacGregor's opinion might be either a slightly sheared sandstone or a slightly sheared psammitic granulite. The locality is near the head of Glen Buck, on the line of the Glen Buck Fault (p. 428) ; if the specimen represents a granulite, it belongs to the metamorphic rocks of Moine type that lie to the east of this fault. The fact that more than three-quarters of the relatively few sliced rocks from Zone *B* prove to have been crushed or sheared to some extent suggests that the incidence of cataclasis in the zone, although much less than in Zones *A* and *C*, is higher than is apparent in the field ; the number of slices available is not, however, sufficient to settle this point.

II. Loch Lochy–Loch Oich Area : Petrographic Notes

(By A. G. MacGregor)

Of eighty-one rock slices from the area,[1] only six within Zones *A*, *B*, *C* show little or no sign of crushing or shearing. Apart from local or prevalent mylonitization in individual specimens, the effects of low-temperature cataclastic retrograde metamorphism are exemplified in the other seventy-two slices by : prevalence of calcite and chlorite ; bent, fractured, and shattered crystals ; lines of shear ; intensely sericitized felspar ; bent and split mica and hornblende ; bleached, chloritized, or " blackened " biotite ; bleached hornblende ; pronounced strain-shadows in quartz ; " mortar structure " associated

[1] One, a highly crushed type, has been omitted from the Table on p. 430 owing to uncertainty as to the zone in which it lies. Three other rocks (uncrushed metamorphic sediments of Moine type) have also been omitted ; they represent outcrops just east of the crush-belt.

with quartz ; and highly sutured mutual junctions between adjacent quartz crystals.

The original nature of a considerable proportion of the sliced material is not determinable in hand specimen. In about one-third of the specimens the cataclastic effects are so severe that, in the microscope slice, the original characters of the rock (or some of them) are often in doubt ; this difficulty arises more particularly in the case of specimens of crushed conglomerate and pebbly grit, even although they may be determinable as such in the field.

The rocks mainly represented are sediments of Old Red Sandstone age (conglomerate, grit, and fine-grained sandstone, with perhaps some shale), and intrusive igneous rocks of Caledonian age (pegmatitic, granodioritic, dioritic, appinitic, and probably lamprophyric). With the crushed igneous types are associated four sheared specimens that probably represent injection-gneisses (31561, 31567, 31568, 33631). The last-mentioned specimens, and most of the igneous rocks, come from a belt (locally about a quarter of a mile broad) near the old railway line (Zone A).

Crushing or shearing that is not severe is seen in seventeen slices (e.g. 31542, 31556, 31566, 31568, 31787, 33625). Rocks that are highly sheared and/or crushed but not appreciably mylonitized are represented by thirty slices (e.g. 31546, 31550, 31562, 31574, 31785, 31789). Rocks in process of mylonitization as indicated by the presence of an abundant streaky development of a mylonite component number sixteen (e.g. 31527, 31528, 31533, 31578).

In a number of sliced rocks mylonitization has gone considerably further (e.g. 31536, 31553 representing igneous rocks). In four other instances the ground-up rock may be described as " gritty ultramylonite ".

Minutely gritty ultramylonitic material, forming a dark, aphanitic flinty-looking veinlet in a crushed dioritic rock, constitutes the only sliced occurrence designated " flinty-crush " by Mr. Eyles (31547 from close to a minor fault in Zone *A*, about three-quarters of a mile east-north-east of the head of Loch Lochy) ; the veinlet, which is rich in somewhat brownish iron-ore dust, but consists mainly of comminuted feldspar and quartz with little or no sericite, affords evidence of intense localized cataclasis.

Three other specimens are composed *wholly* of gritty ultramylonite ; they are hard, grey, compact, somewhat phyllitic-looking rocks (with a crude wavy foliation, but almost flinty-looking on a cross-fracture). These three gritty ultramylonites will be described in some detail because rocks of this character frequently form bands, several feet across, in Zones *A* and *C* (p. 429). They consist of fine sericitic ultramylonite that encloses rounded to sub-angular rock and mineral

fragments. In the thin sections, the gritty fragments range in size from very minute up to about 1 cm. across, and consist of quartz, of feldspar, and of rock-fragments. In one instance, an included fragment can be recognized as a psammitic granulite of Moine type (31523). From the same locality, a pale grey siliceous included fragment (a nodule several centimetres across) was separately sliced ; it appears to be a sheared and crushed Old Red Sandstone (31524.) The outcrop from which these specimens come is close to a minor fault in Zone *C*, about a mile and a quarter south of the head of Loch Lochy ; it is probably composed of mylonitized Old Red sediments including pebbly grits. The other two gritty ultramylonites come from Zone *A*. In one case, small included rock-fragments represent a medium-grained granitic igneous rock containing some muscovite (31792 from the side of the old railway line about three-quarters of a mile south of Invergarry) ; in the other specimen, small partly carbonated rock fragments are so highly crushed and sheared that their origin is indeterminate (33630 from the side of the old railway line about a mile south-south-west of Invergarry).

Three mylonites, from Zone *C*, I have classed as most probably representing original shales (31532, 33626, 33627).

In connection with the mylonitic rocks, attention may be drawn to Dr. Shand's record of a few minute lenticular veinlets of mylonite (1951, p. 426) ; these he recognized, parallel to the lamination, " in thin sections of Moine gneiss " from an unspecified locality (or localities) in the Great Glen zone. He says : " Such veinlets might be found in any hard rock that has been strongly folded. There is no known reason to relate them to the Great Glen Fault." If this kind of mylonite resembles that in Mr. Eyles' slices, I am unable to agree with Dr. Shand's statement ; within my experience bands, streaks, and veinlets of mylonite resembling those exemplified in Mr. Eyles' rock collection have not been formed in the Moine and Dalradian Series of the Scottish Highlands as a result of folding.

There are three sliced examples of quartz-chlorite veinlets, two of which contain some alkali feldspar ; one comes from Zone *A* and two from Zone *B* ; they cut sheared sandstone (33619), sheared grit (31576), and sheared gneiss or granodiorite (33631). It appears to me that the veinlets have crystallized under the same stress conditions that affected the rocks they cut, and that the stress was transverse to the veinlets and outlasted most of their crystallization. Mr. Eyles noted in the field that these veinlets are often associated with, and pass into, quartz-veins, and are characteristically developed in the neighbourhood of faults and crush-lines. He observed also that the sides of the veins appear slickensided, as if movement had continued, or had been repeated, along lines of fracture after they had been infilled

with quartz and chlorite. The *veinlets*, however, show no microscopic evidence of longitudinal shearing. Mr. Eyles states that the chloritic quartz-veins are quite distinct from veins of coarse pegmatite that occur not infrequently within the crush-belt (cf. p. 429, footnote).

On the basis of my examination of Mr. Eyles' rocks and slices, and of the distribution of specimens as shown on his six-inch-to-mile field maps, I am in agreement with the conclusion already formed by him, by Professor Read, and by Professor Kennedy, that there is, bordering the south-east side of the Great Glen in the Loch Lochy–Loch Oich area a broad cataclastic zone characterized by intense crushing and shearing, accompanied by more localized mylonitization.

III. Evidence of Crushing in other parts of the Great Glen

(By V. A. Eyles and A. G. MacGregor)

Both to the north-east and to the south-west of the Loch Lochy–Loch Oich area we believe that broad crush-zones exist on the south-east side of the Great Glen. The evidence is as follows :—

Foyers Area.—Some 21 miles to the north-east, in the neighbourhood of Foyers, the nature and effects of cataclasis along the south side of the Glen have been described by Dr. Mould (1946, pp. 250–1, 256–7, 259, 264). The crushing and its effects appear to be generally similar to the phenomena observed in the Loch Lochy–Loch Oich area. The rocks involved include sediments of Old Red Sandstone age, dioritic igneous rocks associated with gneisses, etc., and rocks of the Foyers Granite Complex itself. The Old Red sediments are unconformable on a gneiss/granulite/mica-schist series, and also on associated highly sheared dioritic and granitic rocks (Creag Nighean Iain Duinn, and Glenlia). This composite belt, comprising sediments on the north-west and igneous rocks and gneisses on the south-east, intervenes between Loch Ness and the locally parallel Glen Liath Fault, situated rather less than three-quarters of a mile from the shore of the loch (1946, text-figs. 1 and 3 and pp. 250–1, 262–4). The Glen Liath Fault separates the rocks just enumerated from the Foyers Granite Complex and associated metamorphic rocks of the Moine Series, to the south-east. Dr. Mould records that the Foyers Complex is traversed by many crush-zones and lines of movement related to the Great Glen Fault. She presents inconclusive evidence that some of the movement was earlier than the Middle Old Red Sandstone (Mould, 1946, p. 256).

A comparison of the Foyers and Loch Lochy–Loch Oich areas is suggestive. It seems possible that the crushed dioritic and granitic rocks of Creag Nighean Iain Duinn and Glenlia, and the associated gneisses, etc., may correspond to the igneous rocks and probable gneisses near the railway line between Loch Lochy and Loch Oich.

In addition, the Glen Liath Fault may be analogous to the Glen Buck Fault.

Fort Augustus Area.—The following note has been contributed by Professor J. G. C. Anderson :—

> " On the south-east side of the Great Glen, south of Fort Augustus, near the Corrieyairack track, and west of the River Tarff, there is a wide belt of intensely crushed rocks which appear to have been, originally, granulites and semi-pelitic schists of Moinian type. The bedding or schistosity has been largely obscured and the characteristic flagginess of such rocks is absent. Chlorite has been developed on a widespread scale. The crushing persists for about three-quarters of a mile south of Ardachy House and then falls off fairly rapidly, indicating the existence of a belt or zone of crushing extending south-eastwards for about half a mile from the side of the Great Glen at that point.
>
> " Immediately north of Fort Augustus, that is, on the north-west side of the Great Glen, Moinian granulites, although showing some crushing, are not nearly so intensely altered, which supports the view that the main fault-zone lies near the south-east shore of Loch Ness."

Tor Castle (*Fort William*) *Area.*—Evidence of severe crushing connected with the Great Glen Fault has been obtained by Mr. G. S. Johnstone of the Scottish Geological Survey, during the course of his official field work in 1949–1951.

On the River Lochy, about 14 miles south-west of the head of Loch Lochy and 4 miles north-east of Fort William, at the big bends in the river at Tor Castle and in adjacent ground to the east, the country rocks (?Moinian) are in a very highly sheared and mashed condition. The evidence so far available indicates the presence of a crush-zone extending for at least half a mile south-east of the general line of the River Lochy above the bends near Tor Castle.

On the opposite (north-west) side of the great Glen in this neighbourhood Mr. Johnstone has found that the Moine Schists (mainly psammitic granulites) are highly shattered, but not greatly sheared, in a zone up to one and a half miles wide.

Loch Linnhe (*Fort William*) *Area.*—Sir Edward Bailey (1934, p. 471) has described certain dark or black schists associated with the Eilde Flags, that form an almost continuous coastal belt on the south-east side of Loch Linnhe for some 9 miles south-west of Fort William. He states that it is impossible to distinguish individual bands consistently " on account of confusion introduced by excessive crushing along the Great Glen (Loch Linnhe) Fault ". He also states : " The foreshore for about a mile south-west of the outskirts of Fort William

shows a pale grey set of schists with what appear at first sight to be beds and lenticles of rusty-weathering sedimentary calcareous schist, the whole affected by terrific breaking and mylonization, hading steeply as a rule towards the north-west. Careful search and comparison show that these grey schists have been derived for the most part from bedded semi-siliceous rock of more or less Eilde Flag type, and that the associated calcareous bands and lenticles are foliated and calcitized (or dolomitized) lamprophyres of Devonian age ; there are also a few porphyrites. In places the mashed mylonized assemblage develops into a foliated crush-breccia that might even be mistaken for boulder-bed. This outcrop is flanked inland by dark schist."

This description leads us to infer that the rocks along the south shore of Loch Linnhe for some distance south-west of Fort William are in a condition comparable with that characteristic of other localities to which we have drawn attention.

We have now set out the evidence, derived from five different areas, indicating (we believe) that the Great Glen, over a lateral distance of some 40 miles between Fort William and Foyers, is flanked on the south-east by a broad crush-belt characterized by intense cataclasis that locally develops into mylonitization.

It is left to our readers to assess the value of the evidence and its significance and to decide : (1) Whether Dr. Shand (1951, p. 426) was, or was not, justified in making the following comment on the rocks of the Loch Lochy–Loch Oich area : " Since the geological relations of these rocks are quite unknown (owing to the unsatisfactory nature of the exposures) they can hardly be considered to throw any light on the problem of the Great Glen Fault " ; and (2) whether Dr. Shand has or has not disposed of the claim that there is in the Great Glen " A broad belt of crushed, sheared, and mylonitized rock up to about a mile in width " (Kennedy, 1946, p. 45).

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CORRESPONDENCE

FORAMINIFERAL ZONES IN THE TERTIARY OF AUSTRALIA

SIR,—I am concerned that in the discussion of certain controversial matters in this correspondence the observed facts should not be overlooked.

Miss Crespin and I have collaborated in recent years in a detailed examination of many sections of Tertiary rocks exposed on the South Coast of Victoria between Torquay and Princetown. I have measured the sections and collected samples systematically from them; Miss Crespin has examined the samples and identified the foraminifera.

We have jointly examined some of the more interesting sections and checked critical evidence. As a result we consider we have obtained much new evidence on the fossil content and correlation of beds below the top of the Jan Juc Formation (Raggatt and Crespin, 1952, pp. 143–7).

Dr. Glaessner (*Geol. Mag.*, 1951, 273–283), stated that his contribution was intended to provide "a tentative framework of zones of definite stratigraphic position in the local as well as in the European time scale". He identified three zones in descending order as follows :—

(3) *Austrotrillina howchini*

(2) *Victoriella plecte*

(1) *Hantkenina alabamensis*

Glaessner also suggested that there may be a "possibility of establishing a zone [of *Sherbornina*] intermediate between the *Victoriella* and *Austrotrillina* Zones" (p. 278).

The principal points of Miss Crespin's criticism of Glaessner's paper, which I desire to emphasize, are :—

(1) That near Torquay *Hantkenina*, *Victoriella*, and *Sherbornina* all occur together in the same bed at the top of the Jan Juc Formation.

(2) That near Torquay *Victoriella* and *Sherbornina* occur also in the lower part of the Jan Juc Formation where, so far *Hantkenina* has not been found.

(3) That between Brown's Creek and Johanna River *Victoriella* occurs in the same bed as *Hantkenina*.

Attention was also directed to certain errors in field observations which it is desirable should be corrected. In the Brown's Creek—Johanna River section—

(1) The beds with *Hantkenina* are not the lowest fossiliferous strata in the Tertiary sequence. Below them are beds with a rich marine fauna; these overlie purple siltstones with *Cyclammina* and, underneath the siltstones are the basal beds of the section (sandstone), the equivalent of Baker's Pebble Point Beds.

(2) As indicated in (1) the *Cyclammina* siltstones ("Anglesean" of Singleton) are below not above the bed with *Hantkenina*.

In his reply to Miss Crespin (*Geol. Mag.*, 1952, pp. 228 and 229), Glaessner suggests that the occurrences of *Hantkenina* at the top of the Jan Juc Formation requires confirmation. This record could only be questioned on the grounds that the fossil is not autochthonous. However, there is no evidence to support this. Six well-preserved specimens have been noted in the Jan Juc material and the assemblage is also significant. It may be noted that *Hantkenina* is not common at either of the other two places in Victoria from which it is recorded, and Glaessner quotes Parr as stating that he had found only one specimen in the material from Maslin Bay.

When Miss Crespin told me that she had identified *Victoriella* in a sample I collected from near Brown's Creek it seemed a natural corollory that *Hantkenina* should be found in the Jan Juc Formation.

The field evidence shows that very broadly the lithological sequence in the lower part of the Tertiary sequence in Southern Victoria in descending order is :—

(3) Calcarenite, limestone and/or calcareous clays and siltstones with a rich marine fauna which includes *Hantkenina*.

(2) Siltstones commonly lignitic and purple in colour with abundant *Cyclammina*.

(1) Medium to coarse quartz sandstone, markedly carbonaceous (including seams of lignite in some places) at the base.

— Jurassic.

The difficulty was that in earlier discussions this general sequence was not well understood ; indeed, as pointed out above, the order of the beds (2) and (3) was reversed by some authors. The correction of this error, the discovery of *Victoriella* at Brown's Creek and of *Hantkenina* at Torquay provide three pieces of evidence which support one another and allow correlation of sections many miles apart to be made with confidence. (Raggatt and Crespin, 1952).

H. G. RAGGATT.

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ACTON,
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8th October, 1952.

LINEATION IN THE SHETLAND ISLANDS

SIR,—In his paper on " A Tectonic Analysis of the Muness Phyllite Block of Unst and Uyea, Shetland " (*Geol. Mag.*, 1952, 263) Dr. D. Flinn gives some interesting particulars with regard to the dimensions of pebbles in conglomerates. So far as the writer knows, such particulars had not previously been given about the constituents of any Scottish conglomerate in an area of lineation, and they have an important bearing on the theory of this subject.

The average dimensions of more than 50 specimens were found to be in the ratio 15·3 parallel to the lineation, 2·3 normal to the lineation, but in the plane of schistosity, and 1·0 across the schistosity. Dr. Flinn infers that if the specimens were originally roughly of the same diameter in all directions, they have been elongated, parallel to the lineation, to about 4·6 times their original length.

In a paper published by the writer in 1948 (*Quart. Journ. Geol. Soc.*, civ, 99) other instances were mentioned where it had been found that lineation and the extension of pebbles were parallel. In most of these cases it was impossible to infer, from the published data, whether the joint direction was *a* or *b*. A description by A. Kvale, however (1945, *Norsk. Geol. Tidsskr.*, xxv, 193) refers to an instance, in the Bergsdalen quadrangle, in Norway, where there is no possible doubt that both the lineation, and the main extension of pebbles. is in the *a* direction.

Dr. Flinn, on the other hand assumes both structures to be in the *b* direction, and explains the extension by rolling. This is the " orthodox " explanation, but it does not seem to be easily intelligible. A pebble in a matrix which is undergoing distortion may be expected to alter its dimensions, but surely it will lengthen them more in the direction of transport than in either of those which are at right angles to it. By " transport " one means the relative movement of two superimposed layers, and if Dr. Flinn is right, this must be either from west to east, or from east to west, corresponding to

what he supposes to be the *a* direction. The pebbles which he describes are, however, lengthened on the average 25° east of north, with a plunge of 24° in that direction.

The lineation of the metamorphic rocks in certain parts of Shetland was studied during the Geological Survey's routine examination of these islands (T. Robertson, 1938, " Observations on the Direction of Lineation in parts of Shetland," *Summ. Progr. Geol. Surv.* for 1936, part 2, p. 75). This applies, in particular, to an irregular belt, running across the group, from Vementry, west of the " Mainland ", to the Outer Skerries, well to the east of the same main constituent, a total distance of about 25 miles. Throughout the belt the direction varies only from nearly due north and south to north-east. Dr. Flinn's lineations, if continued in their own line, would fit in well with Robertson's observations, and one may infer that there is a certain regularity, probably applying to all the lineated part of Shetland.

Reverting to the simile, used in the writer's 1948 paper, of the movement of a pack of cards, lying on a flat table, it may be suggested that the uppermost cards have moved either north or south, in relation to those below. This can only represent very roughly what has happened in Shetland, in view (1) of the lineation dips, and (2) of the large displacements discussed by Read (1934, *Quart. Journ. Geol. Soc.*, xc, 637) and others. It implies an *a* lineation, but appears to the writer to give a better explanation of the extension of the pebbles described than that of Dr. Flinn's paper.

E. M. ANDERSON.

62 GREENBANK CRESCENT,
EDINBURGH.

October, 1952.

MUGEARITES AND OLIGOCLASE-BASALTS

SIR,—My old friend Professor Walker, in his recent article " Mugearites and Oligoclase-Basalts " (*Geol. Mag.*, lxxxix, p. 337), refers to my description of mugearites in " The Geology of North Ayrshire " (*Mem. Geol. Surv.*, 1930, pp. 105–8) but, owing to a temporary oversight (for which he has hastened to express regret by air-mail), fails to direct his readers' attention to p. 89 of that publication, where a reference will be found to a paper entitled " The Classification of Scottish Carboniferous Olivine-basalts and Mugearites " (*Trans. Geol. Soc. Glasgow*, xviii, pt. ii, 1928, p. 324). In this paper I devoted four pages to the history of the classification of Scottish mugearites, and drew attention to H. S. Washington's " olivine-oligoclase-andesites " of Hawaii, to H. H. Thomas's pre-Upper Llandovery mugearites of Pembrokeshire, and to A. K. Wells's views (of 1924) on the classification of mugearites. I dealt with the use of the name mugearite in Geological Survey publications in more detail than Professor Walker, and worked out a comprehensive definition of the term which seems to differ little from the one he now proposes. At a later date I adopted the current view that mugearite is a special variety of trachybasalt (op. cit., 1928, p. 349 ; 1939, p. 89).

Professor Walker's article is timely, and will prove of interest to those who deal with volcanic petrology. I agree that the abandonment of the term " oligoclase-andesite " should be considered by Hawaiian petrologists. I believe, however, that no definition of mugearite will make it less difficult to solve two problems : (1) the naming of rocks transitional from mugearite to fine-grained basalt with fluxional parallelism of feldspars ; (2) the recognition of the original composition of the tiny sub-parallel albitic feldspars of lavas that resemble mugearites but are not " fresh-looking " (op. cit., 1928, p. 348). In the case of (1) the term " basaltic mugearite " is often useful.

A. G. MACGREGOR.

19 GRANGE TERRACE,
EDINBURGH.

13th October, 1952.

THE COVE MARINE BANDS

SIR,—In Text-figure 1 of Mr. H. H. Wilson's paper (*Geol. Mag.*, lxxxix, p. 305) his generalized stratigraphical columns for Berwick-on-Tweed and Redesdale are obviously copied from those published on One-inch Geological Maps Sheets Nos. 2 and 8, respectively. In his Redesdale column, Mr. Wilson replaces the Fourlaws Limestone of the map section with his Redesdale Limestone and omits 150 feet of strata and the Redesdale Limestone beneath the Fourlaws Limestone. I seek his explanation for the above omission, for he makes no mention of the Fourlaws Limestone or its underlying 150 feet of strata in his paper.

Mr. Wilson correlates the Redesdale Limestone and the Redesdale Ironstone Shales with the Woodend and Dun Limestones, respectively. In maintaining that the Fourlaws and Redesdale Limestones, 150 feet apart, do exist, I still support the view that these are the equivalents of the Woodend and Dun Limestones of Berwick, respectively.

W. ANDERSON.

GEOLOGICAL SURVEY OF GREAT BRITAIN,
33 ESKDALE TERRACE,
NEWCASTLE-ON-TYNE, 2.

22nd October, 1952.

MALVERN TECTONICS

SIR,—In the second argument he uses in his recent letter (*Geo. Mag.*, 1952, p. 384) Mr. T. Whitworth states that the Malverns have been a *line* (the italics are mine) of re-current disturbance through very long periods of geological time, and he immediately cites "the nature and physical conditions of the Pre-Cambrian rocks" as confirming their lengthy and complex history, and therefore by inference extends the linear nature of the Malvern Range back into Pre-Cambrian time. He also quotes the unconformable nature of the Cambrian, and of the Silurian, as supporting facts. The available evidence, however, does not prove the apparent linearity we see to-day to be any older than the movements which overturned the Old Red and the Silurian, and even this appearance may be partly due to the one-sided nature of the exposures. The complexity of the Pre-Cambrian is not confined to the Malverns, nor is unconformable Cambrian and the absence of Ordovician.

N. L. FALCON.

BRITANNIC HOUSE,
FINSBURY CIRCUS,
LONDON, E.C. 2.

19th November, 1952.

REVIEWS

A PALAEOGEOGRAPHICAL ATLAS of the British Isles and adjacent parts of Europe. By LEONARD J. WILLS. pp. 64, with 12 plates containing 54 maps. 11 × 8½ inches. London and Glasgow: Blackie and Son, Ltd., 1951. Price 21*s*.

A palaeogeographer, in drawing his maps, is compelled to make decisions over difficult problems that prudence would urge him to leave alone. He must continue his shore lines across country where the evidence is unsatisfactory or even non-existent, and he must decide what to do with awkward empty places. Prof. Wills is unduly modest about the shortcomings of this kind that his maps must share with all other reconstructions of past geography; he might well have pointed out that it is these very gaps and uncertainties that are most likely to set his readers thinking and thus point the way to new research.

The first plate displays two maps showing the main present-day structures of Europe and the British Isles. The setting of Great Britain in the structural plan of Europe is thus well emphasized, but the details would have been much easier to follow if a consistent set of symbols had been used for the two maps. Thus North Atlantis is represented by a grey overprint in Europe, but by red cross-hatching in Britain; Caledonian folds by red trend-lines in Europe, but grey overprint in Britain, and so on. A similar lack of uniformity also detracts from the usefulness of some of the other composite plates, as for example Plates V and XII.

The reconstructions of the Arenig and Lower Bala, placed side by side, bring out in a suggestive manner the importance of the mid-Ordovician earth movements. The Moine Thrust and the Highland Boundary Fault are shown as moving at this time, accompanied by a general uplift of the Scottish Highlands. The possibility, mentioned in the text, that the Borrowdale Volcanic Series may have been piled up above sea-level, is perhaps a slender justification for marking the Lake District as land during the Caradocian.

The maps illustrating the Silurian and Devonian form an interesting and instructive series, although some stratigraphers will disagree with certain of the details. The inset maps of Europe in Plate V are useful, and would be more so if the marine facies were not marked with the shading used elsewhere on the plate for the Old Red Sandstone. Plate IV is a very successful map of Caledonian structures in the British Isles during the Lower Palaeozoic. It gives a clear picture of the author's views on this difficult subject, and puts a proper and refreshing emphasis on the earlier phases of the orogenic movements involved. A substantial area of pre-Arenig folding is centred on the Irish Sea, with a suggestion of smaller areas in Brittany and Cornwall, and the pre-Bala movements are shown as affecting almost the whole area from the Lake District and Clew Bay to the Moine Thrust. The author accepts a mid-European branch of the geosyncline, running beneath east Yorkshire and East Anglia and leaving the Welsh branch near Horton-in-Ribblesdale; the text, however, warns the reader against too readily adopting this reconstruction. An inset map shows Kennedy's displacement of northern Scotland along the Great Glen Fault, but the other maps of early Scotland appear to work out quite satisfactorily on a more conventional framework.

Two particularly interesting maps reconstruct the Carboniferous grit deltas, one showing the depositional limits of individual grits and the other giving isopachytes for the whole Namurian. The introduction of isopachytes into the map of the Lower Westphalian also adds substantially to the value of Plate X. The two maps illustrating the Permian are, perhaps of necessity, more speculative than most of the plates in the atlas; the author claims more for the Early Permian than many stratigraphers would be willing to admit, and the breccias of the Lake District and the Pennine country seem rather over-worked in being made to supply evidence for the presence of both early and late Permian.

Perhaps the most attractive map of all is that representing the Middle

Bunter, with its simple picture of sands and gravels washed down from the Triassic uplands and spreading out over the desert plains.

In future printings of the atlas, it is to be hoped that the register of the grey and red overprints may be improved. Individual atlases show varying degrees of misplacement, particularly of the red plate. In the copy under review, for example, the error in printing Plate XVII is sufficient to make the Wealden river pass along the Bristol Channel, instead of close to Dartmoor, which was doubtless the author's intention.

In his preface, Prof. Wills expresses the hope that the pages of his atlas may help to bring to life the long-buried geographies of the past. In this the atlas is triumphantly successful ; and however much the reader may disagree on points of detail, or wish for minor improvements, he can hardly fail to find a study of these maps both stimulating and illuminating.

M. B.

GRUNDLAGEN DER BIOSTRATONOMIE. By A. H. MÜLLER. Abhandlungen der Deutschen Akad. der Wissenschaft zu Berlin (Klasse f. Math. und Naturwiss. 1950, no. 3) Akademie-Verlag Berlin. 147 pp. (4to) with 26 tables and 79 figs. 1951. Price 16.50 DM (paper bound).

Biostratigraphy (perhaps preferable to the more obvious anglicization of the title) is a comparatively recent development of geology in which attention is focussed on the relationship between the fossil and the sediment in which it occurs. It has nothing to do with stratigraphical palaeontology as commonly understood, nor is it palaeo-ecological ; but it concerns all the processes between the death of an animal and its preservation as a fossil. Here are brought together for the first time the principles of this new science, which has developed mostly in Germany during the last thirty years, illustrated by an extremely useful bibliography of some 300 references. The main sectional headings of this manual will give some idea of its scope ; causes of death : the fate of the organic substances of the body : the fate of the hard parts before final embedding (including recognition of the effects of predatory animals) : autochtonous and allochtonous embedding (including mechanical sorting and orientation of shells etc.) : and changes accompanying early stages of diagenesis of the sediment. Attention to these aspects of a fossil helps to make it " come alive " and shows how much " animal interest " can sometimes be deduced from the record of the rocks ; the book certainly fills a gap in palaeontological literature.

O. M. B. B.

RADIOCARBON DATING. By WILLARD F. LIBBY. pp. vii + 124, with 11 figures. Chicago : The University of Chicago Press (London Agents : The Cambridge University Press), 1952. 25*s*.

Dr. Libby, who is professor of Chemistry at the Institute for Nuclear Studies in the University of Chicago, gives a detailed description of his experimental methods for determining the concentration of radioactive carbon. In brief, the purified carbon dioxide prepared from the crude sample is reduced to elementary carbon, which is spread on the cylinder of a specially constructed and screened Geiger counter. The standard counting time is limited to 48 hours.

There are chapters dealing with the principles and assumptions underlying the use of these results for calculating the age of the samples, and a chapter setting out a selection of results in tabular form. Most of the determinations were made on plant material such as wood or charcoal, the skeletal remains of animals giving results that are regarded with suspicion. Nevertheless, reliable determinations can be made upon the dung of herbivores, and two samples attributed to the giant sloth, one from Nevada and the other from southern Chile, both gave ages between 10,000 and 11,000 years. One of the most surprising results gives an age of a little more than 1,000 years for viable seeds of *Nelumbium*, collected from a peat bed in Manchuria ; several hundred of these seeds have been successfully germinated. M. B.

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Rocznik Polskiego Towarzystwa Geologicznego (Ann. Soc. géol. de Pologne), xxi, fasc. 1, Krakow, 1951. Zl. 17. (Comprising *Mollusques du Sarmatien de la Volhynie*, 1 ; *Gastropodes* (with French summary) and *The old crystalline formations of the Sudeten Mountains* (with English summary)).

Spe!eon : Revista Espanola de Hidrologia, Morfologia, Carstica y Espeleologia. Tomo iii, num. 1, 2. April, 1952. (Universidad de Oviedo ; Facultad de Ciencias.)

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